Evaluation of Experimental Station Potentials in a Shared Facility: Focus on the Combined Use of Stations

Keiichi Shinbe

Department of Social Intelligence and Informatics
Graduate School of Information Systems
The University of Electro-Communications/JASRI
Tokyo/Hyogo, Japan
Email: shinbe@spring8.or.jp

Kosuke Shinoda

Department of Social Intelligence and Informatics
Graduate School of Information Systems
The University of Electro-Communications
Tokyo, Japan
Email: kosuke.shinoda@uec.ac.jp

Hirohiko Suwa

Ubiquitous Computing Systems Laboratory
Graduate School of Information Science
NAIST
Nara, Japan
Email: h-suwa@is.naist.jp

Satoshi Kurihara

Department of Social Intelligence and Informatics
Graduate School of Information Systems
The University of Electro-Communications
Tokyo, Japan
Email: skurihara@uec.ac.jp

***Abstract*—The large synchrotron radiation facility SPring-8 in Japan is a shared research facility opened to domestic and foreign researchers of industry, government, and academia. It is used for research and development in a wide range of fields. This facility must be efficiently operated and must have substantial research outcomes because national grants are used to fund its operation. This paper creates a visual of how the experimental stations in the facility were used over time on the basis of the SPring-8 publication database. It aims to clarify which experimental stations are used in combination to create research outcomes. A network analysis showed that each experimental station can be classified into groups: a group with many research outcomes, a mediating group that supports research by other experimental stations, and a group specialized for combined use with specific experimental stations. It also became clear that there is a difference in the publication productivity of each group.**

Keywords–Shared Research Facility; Complex Network; Cluster Analysis; Visualization; SPring-8.

I. INTRODUCTION

Shared research facilities in Japan are financed by the national treasury. For this reason, such facilities must maximize their research outcomes and contribute to academic progress and social and economic development. Optimizing facility services with a limited budget and staff is also important. To improve facilities and their proposal systems, it is necessary to determine whether experiments conducted have had corresponding research results. In most cases, for shared research facilities that have only recently started operation, those in charge of the facility prioritize tracking usage trends such as the operation time of the facility and the number of users. The evaluation of research outcomes by facility-use is often conducted after the facility has been in operation for several years. Also, in many cases, those in charge of the facility evaluate mainly on quantitative values such as the number of published papers or citations. Therefore, there is not much analysis of research outcomes derived from the combined use of experimental stations in facilities.

This research aims to present a new perspective by evaluating experimental stations in addition to conventional quantitative indicators. We analyzed the database in which the results of research conducted at SPring-8 [1] are registered. SPring-8 is a shared research facility open to domestic and foreign researchers in the fields of industry, government, and academia.

This paper ’ s main contributions are as follows: first, we closely examine how the interactions between experimental stations changed over time, and extracted some characteristic network structures; second, we visualize the publication productivity of each experimental station and classify them into several groups; third, we present the potential for creating research outcomes as a general indicator for each experimental station whose position cannot be evaluated by its number of associated publications alone.

In Section 2, we give an overview of SPring-8 and its publication database. We then discuss related work in Section 3. In Section 4, we explain how we visualized the potential for creating research outcomes. In Section 5, we focus on unique structures in the complex network of beamline interactions and classify the beamlines into four groups on the basis of publication productivity. By the analysis results, we discuss future subjects for research in Section 6.

II. OVERVIEW OF SPRING-8

SPring-8 is a large synchrotron radiation facility constructed in the west of Japan that started operation in October 1997. More than 15,000 researchers come to SPring-8 annually, and more than 2,000 experiments in a wide range of fields, such as material science, earth science, life science, environmental science, and industry (in other words, research proposals) are conducted every year.

 ISBN: 978-1-61208-620-0

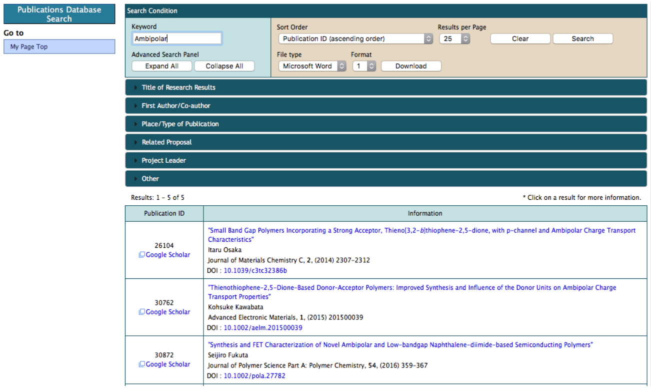

Figure 1. SPring-8 Publication Database.

This facility has multiple experimental stations with different characteristics; these experimental stations are called “beamlines” [2]. In a beamline, high-intensity light (radiation light) is spectroscopically divided (taken out into the light of a specific wavelength), and a measurement sample is irradiated with it. Researchers who want to use this facility prepare an application form describing which experimental station they wish to use, for what purpose. They need to submit their proposal on the user portal website “SPring-8 User Information” [3] before the deadline that is twice a year. The main items of the application form are shown below.

- Experimental Details
- Research Area
- Research Method
- Project Team Members
- Samples
- Requested Experiment Time
- Preferred Beamline

After the deadline, proposals are reviewed from the perspectives of scientific validity, technical feasibility, and experiment safety. After these assessments, the proposal review committee makes a final decision on whether or not to approve each proposal.

Beamlines are classified into three types depending on the researching party by whom they are intended to be used. In this research, we analyze the potential for creating research outcomes of 26 public beamlines that were built for researchers to use generally and 18 contract beamlines that were constructed by research proposers (consisting of domestic and foreign industries, academia, and government) for their own continuous use.

A beamtime fee corresponding to usage time is charged after each experiment. However, if researchers publish their research results in a refereed journal article, etc., within three years of the experiment and register information such as the article title in the SPring-8 publication database, the beamtime fee is waived.

The research result information of SPring-8 is open as a database on the User Information portal [4], and it is possible to search by specifying article title, author name, journal title, proposal term, and other such terms (Figure 1).

Although it is not possible to directly access the article content from each search result, if the article ’ s digital object identifier (DOI) has been registered, users can navigate to the website of the corresponding publisher manually.

III. Related Work

As a precedent network analysis, Yamashita et al. predicted trends in the information of academic fields using information from applications for Grants-in-Aid for Scientific Research [5]. Also, Érdi et al. analyzed a temporal change in the structure of a cluster based on the citation information of US patents [6]. Cho and Shih identified core and emerging technologies in Taiwan from a patent-citation network in order to pursue competitive advantages [7]. In addition, studies that trace the transition of research trends and predict research domains expected to develop in the future by analyzing the network of cited works and references have been conducted in various research fields [8]–[11].

National Institute of Science and Technology Policy in Japan (NISTEP) extracts high-attention research areas on the basis of citations in other articles and depicts the results in a “Science Map” [12]. With this map, one can understand the changes over time in research trends around the world and domestically with a visual similar to a heat map. One can also visually compare the competitive research areas of each research institution. However, this is not suitable for analyzing the potential for creating research outcomes from experimental stations in a single facility because this map comprehensively shows competitive domains of an entire research institution.

Major synchrotron radiation facilities in the world publish a booklet summarizing research highlights every year [13]–[15]. From this information, it is possible to roughly understand the latest trends and outcomes in each research domain at each synchrotron radiation facility. However, there are few studies that analyze from multiple perspectives how experimental stations in a shared facility are used in combination and whether combined use creates research outcomes.

In this research, on the basis of the SPring-8 publication database, we conduct network analysis to clarify the mutual relationship between beamlines that contributed to research outcomes. In short, we arrange each beamline as a node in a network diagram and connect the nodes if there is combined use of the beamlines. This connection is depicted as an edge. By analyzing the temporal changes in this beamline network, we can evaluate each beamline not only by its number of associated publications but also by the presence of nodes that contribute to outcomes. Further, in order to visualize the differences in trends between public and contract beamlines, the node shape of the two beamline types is distinguished.

IV. Methodology of Visualization

Here, we present the procedure for visualizing the potential for creating research outcomes of each beamline using a network analysis of the data accumulated in the SPring-8 publication database. We analyzed the research results (9,126 records) and related proposals (21,277 records) published between January 1, 2006 and September 30, 2017 and registered in the database by 13 October 2017. Then, we prepared separate data for every three years from 2006 in addition to the overall data and analyzed the overall trend and the changes over time. All data used in this analysis are open information that can be found in the SPring-8 publication database.

 ISBN: 978-1-61208-620-0

A. Structure of SPring-8 Publication Database

The SPring-8 publication database consists mainly of the following items.

- Publication Title
- Type of Publication
- Place of Publication
- Author Information (First Author, Coauthor, Corresponding Author)
- Related Proposal Information

Besides publications in refereed journals, activities such as oral presentations, poster sessions, and invited talks can also be registered in the publication database. However, the beamtime fee is only waived when a publication is registered in the categories of "refereed journals, dissertation, refereed proceedings," "SPring-8 research report," or "corporate technical journal" [16]. In this research, we analyze the registration data of publications that satisfy these criteria for approval as a "dissemination of research results."

In the publication registration form, in addition to the publication title, there is a column for registering related proposal information corresponding to past research results, and multiple items of related proposal information can be registered for each research result. When doing so, it is necessary to enter the proposal number that uniquely identifies the research proposal to be used. From this number, it is possible to identify the beamline used in the experiment.

B. Calculation of Nodes and Edges

If a research result (article) is derived from multiple proposals, it is considered that a single beamline more than twice or different beamlines were used. In other words, by depicting a network with edge co-occurrence of beamlines used in research outcomes, the nature of each beamlines' contribution to research outcomes can be represented visually.

We calculated values of nodes and edges according to the following procedure (Figure 2).

1) Record beamline(s) from related proposals for each registered publication.
2) Enumerate combination(s) of beamlines included in the same registered publication.
3) Count total number of registered publications for each beamline. This value corresponds to node size.
4) Count total number of registered publications for each beamline-pair combination. This value corresponds to edge width.

C. Visualization of Combined Use with Beamlines

An undirected graph was created using the beamlines of related proposals as nodes and the combination of beamlines as edges. The graph-drawing algorithm used a spring model. We represented the number of publications registered for each beamline with the size of the node and the number of publications derived from the combined use of multiple beamlines with the width of the edge. Public beamlines were plotted as circles while contract beamlines were plotted as squares; this way, the difference in the interaction depending on the beamline type could be identified.

A weak connection between the nodes indicates that the frequency of combined use of the beamlines is low. Because

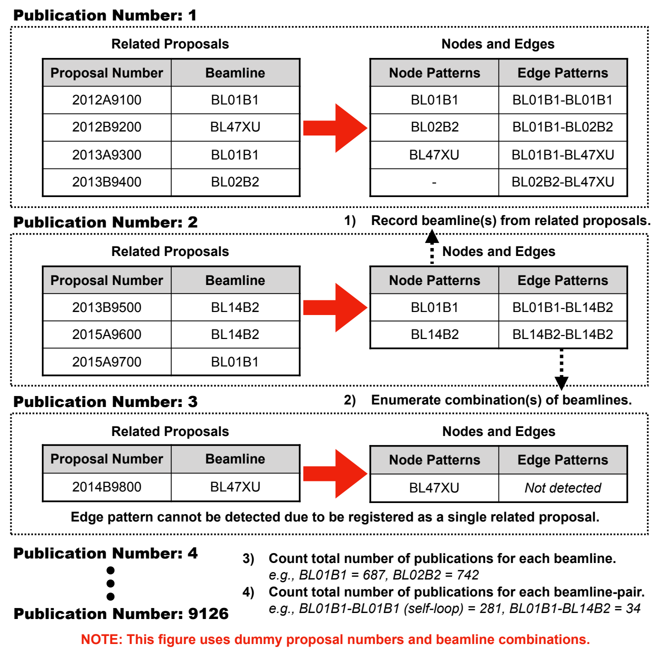

Figure 2. How to Count Nodes and Edges.

these networks have a low impact on research outcomes, we excluded edges with less than five publications over the entire period. However, in the network in which the aggregation period is divided into three years, the edges that are not included in the overall period are drawn on the network even if the number of registered publications in the beamline-pair is less than five.

D. Visualization of Publication Productivity

The proportion of articles associated with each beamline to the total number of registered publications is plotted on the x-axis. The ratio of the edge of each node (degree) to the maximum edge number, i.e. the edge co-occurrence rates of the beamline, is plotted on the y-axis. We define the coordinates of each beamline in this graph as publication productivity.

V. Results and Discussion

Figure 3 shows the beamline network that is based on the related proposals of registered publications issued between 2006 and the end of September 2017.

From the total number of edges and registered publications, it can be seen that the mutual relationship between beamlines is stronger for public beamlines than for contract beamlines. Many public beamlines occupy the central part of the network while contract beamlines are satellites in the peripheral part. Further, some contract beamlines were isolated from the network of beamline connections, and most of the approved proposals were conducted with a single beamline. Figure 3 also shows that beamlines with little combined use with other beamlines have a relatively low number of publications. As for beamlines with a large number of publications, nodes with high degrees such as BL01B1 and BL02B2 are in the center of the network, while structures that use a small number of beamlines in combination intensively like BL38B1, BL41XU and BL44XU are also seen. In this way, the existence of a clique is recognized between beamlines that have relatively

 ISBN: 978-1-61208-620-0

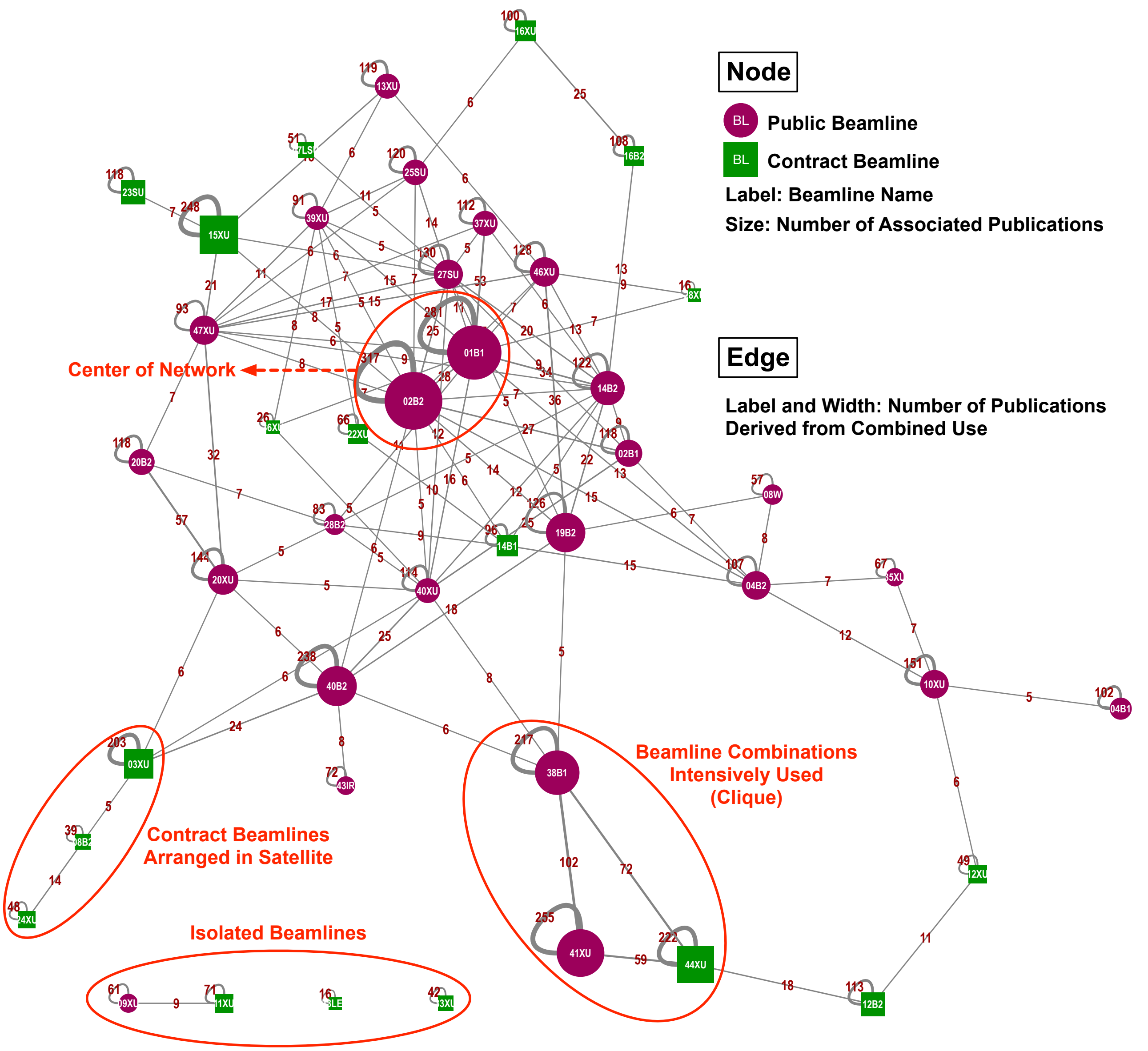

Figure 3. Beamline Network Based on Related Proposals of Registered Publications (Publication Year: 2006-2017).

low degrees but a large number of publications. In this case, “clique” means that the three nodes are connected to each other by edge. The clique in the beamline network seems to indicate compatibility of experimental equipment to some extent. These results suggest that when a specific beamline is crowded with proposals and the requirements of the measurement object are met, a change to another beamline may be possible. Therefore, if it is anticipated that a beamline in a clique has a high ability to produce outcomes and the demand in the future is expected to be strong, it will be possible to consider adding additional beamlines of the same specifications. The cliques in which the number of registered publications between each node by beamline-pair is 12 or more are listed in Table I.

Additionally, we divided the aggregation period into every three years from 2006 on the basis of publication year in order to compare how beamline combinations changed over time. Table II shows the cluster coefficients by period, average

TABLE I. TYPICAL CLIQUES IN BEAMLINE NETWORK

No.	*Beamline 1*	*Beamline 2*	*Beamline 3*	*Total Publication Count*[*1]
1	BL38B1	BL41XU	BL44XU	197
2	BL14B2	BL19B2	BL46XU	71
3	BL01B1	BL14B2	BL40XU	60
4	BL01B1	BL02B2	BL04B2	54
5	BL14B2	BL27SU	BL40XU	26

[*1] Calculated the unique number of publications including at least two beamlines related to each clique.

degree, number of nodes, and number of edges (excluding self-loops). We computed these values by using the complex network visualization software Cytoscape [17] and built-in plugin NetworkAnalyzer [18].

From these indicators, the network showing the mutual relationship between beamlines is sparse as a whole from

TABLE II. CLUSTER COEFFICIENT, AVERAGE DEGREE, NODE AND EDGE COUNT FOR EACH PERIOD

Periods	*Cluster Coefficient*	*Average Degree*	*Node Count*	*Edge Count*[*1]
2006-2008	0.068	2.02	39	20
2009-2011	0.249	4.00	42	65
2012-2014	0.293	5.36	44	96
2015-2017[*2]	0.303	5.16	44	92
Entire Period	0.299	5.45	44	98

[*1] Self-loop edges were excluded from the Edge Count.
[*2] Based on calculated values until September 2017.

2006 to 2008, and there was only one clique corresponding to the No. 1 combination of Table I. However, in the 2009 to 2011 period, the network structure grew large, combined use of beamlines increased considerably, and cliques No. 2 and 4 appeared. The number of clusters and edges increased in 2012 to 2014, and the existence of all the cliques in Table I was visible at this point. However, in the last three years, the network structure saturated and no significant change was observed as an indicator. This is likely because the number of approved proposals, operation time of the facility, and beamlines in operation (nodes) have not changed significantly in recent years.

The proportion of the number of registered publications for each beamline to the total number of publications (9,126) is plotted on the x-axis. The percentage of combined use among other beamlines, i.e. the degree of each node divided by the maximum number of edges (43) in the network, is placed on the y-axis. Each point is drawn as a scatter diagram (Figure 4).

The graph of publication productivity shows that beamlines can mainly be classified into the following four groups.

- High-Performance Group
- Mediating Group
- Specialized Group
- Low-Performance Group

The triangular dotted line indicates beamlines for specialized applications. Some such beamlines include industrial-use beamlines and protein crystallography beamlines whose main application is a routine measurement of protein structure analysis.

The high-performance group is a beamline group with a large number of registered publications and nodes with high degrees. As can be seen from Figure 3, it is in the center of the network and is active in combined use with other beamlines, but there are also a large number of publications that come from multiple uses of the same beamline. In beamlines included in this group, a general-purpose measurement method called X-ray absorption fine structure (XAFS) is available. Its use for general purposes in a wide range of research fields is likely a factor leading to the group's high performance.

The mediating group has relatively few registered publications, but has active combined use with other beamlines, which suggests that this group supports the research outcomes of other beamlines. In this group, nodes have relatively high degrees, and it is difficult to identify cliques. In other words, the combined use of three or more beamlines is not common. Therefore, it is presumed that beamlines in this group are also utilized for preliminary experimental measurements in various research fields.

Beamlines included in the specialized group are highly capable of creating research outcomes, but they are characterized by limited combining with other beamlines. In other words, it is a group that easily creates cliques, such as the No. 1 beamline group in Table I. This beamline group is contained in a triangle dotted line indicating that it has a specific application type, and contains most of the beamlines capable of the routine measurement called protein crystal structure analysis. It is thought that the connection with beamlines used in other research methods and fields is sparse for this reason.

The low-performance group has few publications, and its association with other beamlines is weak. The fact that many contract beamlines are in this group is considered to be one reason that the publication productivity of contract beamlines is relatively lower than that of public beamlines. Contract beamlines were initially built by research proposers on the premise that they would be used for specific research, so this group is not generally considered for a wide range of use by researchers other than stakeholders. However, the installation space for beamlines is limited, and it is essential to continually create research outcomes commensurate with the beamtime because government grants are being used in the construction and operation of the entire facility. Because there are beamlines specialized for research in specific areas with few contact points with other fields, they should not be evaluated only by their associated number of registered publications. But, the potential for creating research outcomes in this group would be improved by promoting interaction with other beamlines.

VI. CONCLUSION

In this research, on the basis of data registered in the SPring-8 publication database, we visualized the correlations between beamlines and the potential for creating research outcomes from each beamline. As a result, the edges in the network increased with time, and we found that new outcomes were created as a result of using various beamlines in combination. We also found that the beamline network includes some clusters such as a group with a large number of publications, a group that indirectly supports the outcomes of other beamlines, and a group that forms a clique structure with strong connections between specific beamlines. It is essential to consider measures for improving the performance of beamlines (nodes) with low degrees and few registered publications. Our research will be helpful as one method for deciding which beamlines to renew when planning a SPring-8 upgrade program.

However, in this research, we do not mention the differences in beamtime required for creating publishing results for each research area and the quality of the research outcomes. Therefore, to deepen the evaluation of individual beamlines, it will be necessary to consider the impact that research outcomes conducted using each beamline has had on academia and society and the adaptability of the beamlines to high-growth-potential fields in the future. We aim to further this analysis by including external indicators such as the ranking of academic journals (e.g., impact factor) and the number of cited articles for each registered publication. We also intend to analyze the similarities between registered publications using the metadata of the publication database and adding the originality of publications as a perspective to consider when evaluating the beamlines.

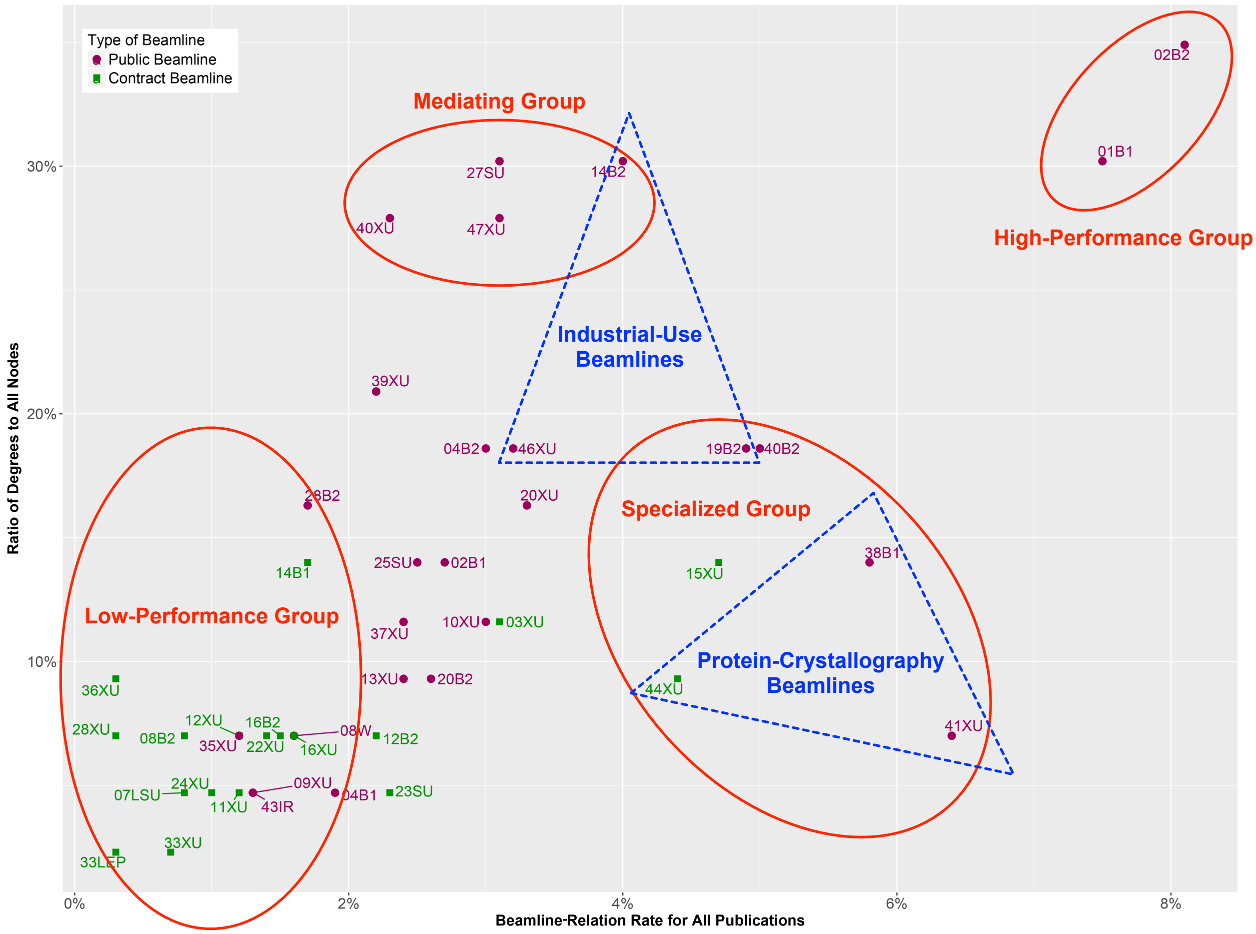

Figure 4. Relation Rate of Beamlines for All Registered Publications and Ratio of Degrees to All Nodes (Publication Year: 2006-2017).

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