Systematic Layout Planning of a Radiology Reporting Area to Optimize Radiologists' Performance

Guilherme Brittes Benitez¹ · Flavio Sanson Fogliatto¹ · Ricardo Bertoglio Cardoso¹ · Felipe Soares Torres² · Carlo Sasso Faccin² · José Miguel Dora³

Published online: 28 November 2017
© Society for Imaging Informatics in Medicine 2017

Abstract Optimizing radiologists' performance is a major priority for managers of health services/systems, since the radiologists' reporting activity imposes a severe constraint on radiology productivity. Despite that, methods to optimize radiologists' reporting workplace layout are scarce in the literature. This study was performed in the Radiology Division (RD) of an 850-bed University-based general hospital. The analysis of the reporting workplace layout was carried out using the systematic layout planning (SLP) method, in association with cluster analysis as a complementary tool in early stages of SLP. Radiologists, architects, and hospital managers were the stakeholders consulted for the completion of different stages of the layout planning process. A step-by-step description of the proposed methodology to plan an RD reporting layout is presented. Clusters of radiologists were defined using types of exams reported and their frequency of occurrence as clustering variables. Sectors with high degree of interaction were placed in proximity in the new RD layout, with separation of noisy and quiet areas. Four reporting cells were positioned in the quiet area, grouping radiologists by subspecialty, as follows: cluster 1-abdomen; cluster 2-musculoskeletal; cluster 3-neurological, vascular and head & neck; cluster 4-thoracic and cardiac. The creation of reporting cells has the potential to limit unplanned interruptions and enhance the exchange of knowledge and information within cells, joining radiologists with the same expertise. That should lead to improvements in productivity, allowing managers to more easily monitor radiologists' performance.

Keywords Radiology · Facilities layout · Systematic layout planning · Radiology health operations

Introduction

The increasing demand for medical imaging studies experienced in past decades was not accompanied by a proportional increment in the number of certified radiologists [1]. Consequently, waiting lists for outpatient imaging and unreported queues are common problems in radiology departments worldwide. Optimizing productivity in such context becomes a healthcare system priority, which should be pursued using proper analytical tools [2–5].

Several indicators have direct impact on the productivity of a Radiology Department (RD), one of the most important

being the reporting turnaround time [6]. The turnaround time is a function of RD resources and operational characteristics, including (but not limited to) the availability of voice recognition systems, radiologists' ability to report outside their main expertise, the occurrence of unplanned interruptions, and the design of the workplace. Efforts to plan and design a dedicated workplace for radiologists have been described [7, 8] with emphasis in achieving an optimized layout of the reporting room [9].

The layout problem is characterized by selecting the best spatial positioning of facilities, such as equipment and working stations, in a specific area. Planning a proper layout is key in attaining efficiency in the production of goods or services, since the layout directly affects the performance of processes and operations carried out in the site [10]. The facility layout problem is defined as an optimization problem that aims at obtaining more efficient layouts by taking into account various interactions between facilities and materials handling systems [11].

In a healthcare context, it is important to develop a holistic approach, in order to combine architectural and legal aspects with logistics related to patients, personnel, and material flows

✉ Guilherme Brittes Benitez
guilherme.benitez@hotmail.com

¹ Industrial Engineering Department, Universidade Federal do Rio Grande do Sul, Avenida Osvaldo Aranha, 99, Porto Alegre, RS 90035-190, Brazil

² Radiology Division, Hospital de Clínicas de Porto Alegre, Porto Alegre, Brazil

³ Health Operations Unit, Hospital de Clínicas de Porto Alegre, Porto Alegre, Brazil

inside the hospital building [12]. While factory layout planning emphasizes the flow of materials, in healthcare systems, the flow of people and information plays a more important role. In both cases, systematic layout planning (SLP)'s tools are applicable. SLP is a method for layout design [13], which seeks to identify among several alternative layout proposals, the one that best fits the department's operational procedures and the institution's strategies [14].

The layout problem in healthcare facilities can be deployed in two levels, both approachable by SLP tools. In the macro level, the goal is to optimize the assignment of functional departments, wards, surgery rooms, and other necessary supporting areas to locations inside the hospital. The micro level is related to the planning of a single functional department in the building [15], such as the Radiology Department. The aim of this study is to describe the development of an optimized layout for the reporting room of the RD at a university hospital.

Methods

Setting

The study was conducted at the Radiology Department of the Hospital de Clínicas de Porto Alegre (HCPA). HCPA is an 850-bed, tertiary care teaching public hospital in Porto Alegre, Brazil. The HCPA's Ethical Committee has approved this study, and authors have complied with the recommendations of the Declaration of Helsinki.

HCPA's RD has 40 part-time radiologists producing nearly 150,000 reports/year, including outpatients, inpatients, and emergency orders. Radiologists reporting groups are divided in seven subspecialty areas: abdominal, thoracic, neurologic, musculoskeletal, head & neck, cardiac, and vascular imaging. All radiology reports are performed using voice recognition through a radiology information system (RIS, IMPAX®, Agfa Healthcare) integrated with the hospital's information system (HIS, AGHUse, HCPA, Brazil).

The radiology reporting area and its surroundings are distributed in 120 m², which includes a reception, an administrative wing, and a reporting room. One of the drivers of this study was an expansion project planned for the RD, which was viewed as an opportunity to improve the current layout using formal analytical tools. Thus, a total area of 274 m² was considered in our study, including the planned expansion of 154 m². The current layout presented in Fig. 1 has several drawbacks. There is a considerable level of noise due to the intense flow of people—both radiologists entering the department and preparing to work, and customers looking for assistance on specific reports—through the reporting room. Assignment of radiologists to working stations is random, which impairs information sharing among specialty peers.

ORIGINAL LAYOUT

SUBTITLE

- 1-ENTRANCE/RECEPTION
- 2-ADMINISTRATIVE AREA
- 3-ADMINISTRATIVE RELAX AREA
- 4-RADIOLOGISTS ROOM
- 5-LOCKER ROOM
- 6-RADIOLOGISTS RELAX AREA
- 7-RESTROOM
- 8-SPACE FOR NEW LAYOUT

Fig. 1 Baseline radiology division reporting layout

Finally, the proportion of the total area assigned to administrative functions is excessive. Radiologists, architects, and hospital managers were deemed major stakeholders and were consulted during different stages of the new layout definition.

Layout Planning

The analysis of the RD reporting layout was carried out using systematic layout planning (SLP) tools. In the initial steps of SLP, a multivariate cluster analysis was used to define groups of radiologists with similar expertise, to be positioned in dedicated working cells.

SLP is implemented in three macro-phases: analysis, research, and selection. The main step in phase 1 is the analysis of proximity requirements between sectors or departments to be positioned in the layout, which is carried out using a relationship diagram. Results from this analysis are the input in phase 2, in which layout alternatives are created considering practical constraints. Alternatives created are evaluated in phase 3 in search of the best layout [16].

Data Gathering

Mapping of activities performed in the sector was carried out using the PQRS (Product, Quantity, Routing, Supporting Services, and Time) analysis, upon adapting the SLP tool to our needs. As the healthcare layout problem prioritizes the flow of people and information [17, 18], mapping of activities included the number of radiologists, types of exams reported, radiologists' output by exam type, number of workstations to

be positioned in the future layout, and radiologists' working scales.

SLP Analysis

- Clustering

Using group technology principles from lean manufacturing [19], we organized radiologists in working cells according to their processing similarities. Cluster analysis was used to identify groups of radiologists. Clustering variables were the percentage frequency of reports on each exam subspecialty area performed by radiologists, based on their historical reporting logs obtained from the RD's Information System. Exams were classified in the following subspecialty areas: abdominal, thoracic, neurologic, musculoskeletal, head & neck, cardiac, and vascular imaging.

We performed a two-step cluster analysis. First, a hierarchical cluster analysis was performed aimed at determining the ideal number of clusters (say, k) of radiologists. Once that number was defined, a k -means analysis was performed to assign radiologists to the k clusters. All analyses were run using Matlab™ (Version R2015a, The MathWork Inc., USA). Hierarchical clustering was based on the average Euclidean distance between individuals (average linkage clustering), while k -means was based on the squared Euclidean distance between centroids. All other settings were configured to standard values defined by Matlab™.

Historical data from 31 radiologists were analyzed in the clustering step, with results available in Table 1. Nine additional, recently hired radiologists were assigned to resulting clusters a posteriori, based on expert opinion from RD managers. A total of four clusters of radiologists were obtained, each cluster devoted to a group of subspecialties.

- Relationship analysis

One of the main steps in SLP is the analysis of relationships between pairs of layout elements, which may be sectors, working cells, or facilities, for example. One way to run the analysis is based on the stated preference of analysts regarding proximity between pairs of elements, which are presented in a relationship diagram. Preferences are evaluated using a coded scale, with codes A, E, I, O, U, and X. The importance of the proximity between a given pair of elements decreases from A (absolutely necessary) to U (unimportant); X is used to denote a situation in which proximity is not desirable.

- Space requirements and availability

To complete SLP's Analysis phase, a meeting was held with the group of stakeholders to determine physical spaces

(needed and available) for the new RD reporting layout and estimate the desired dimensions for the department's elements. The analyses used plants in which the current layout and the future available area of 274 m² were displayed.

SLP Research

The information gathered to prepare layout alternatives included space limitations, demands of each sector, and their singularities, some of them related to personnel's preferences [20]. Layout alternatives were generated constructing a space relationship diagram. Following meetings with radiologists and hospital architects to analyze initial layout proposals, additional demands, and elements were considered to generate new layouts; they were (i) possible changes in the positioning of elements for better use of space, (ii) availability of windows in some areas (iii) assignment of an area to place an HVAC equipment, and (iv) flows of users and information in future layout propositions.

SLP Selection

In the Selection phase layout alternatives generated in previous phases were evaluated. The objective is to select the best layout alternative. After applying SLP to obtain layout alternatives, they should be compared against each other and the original layout. Upon selection of the best alternative, the final layout plan is detailed, identifying the final location of elements such as machinery and equipment, partitions between working cells, and power connections as electricity, water, and gas [21].

Results

Clustering

Through cluster analysis, radiologists were grouped in the following four reporting clusters, based on historical exams' reporting logs from each radiologist: cluster 1—abdomen; cluster 2—musculoskeletal; cluster 3—neurological, vascular, and head & neck; cluster 4—thoracic and cardiac. Table 1 presents the list of radiologists (coded M1 to M31), their percentage historical worktime reporting in each subspecialty area (calculated over a 20-month period), and their initial and final cluster assignment. The initial assignment was the one obtained through cluster analysis using the k -means algorithm; the final assignment was defined by RD managers, aiming at balancing the available workforce across subspecialties. Distance from cluster centroids is also informed in the table, for both assignments. Small distances are desirable, but there is no threshold value.

Table 1 Results from cluster analysis on radiologists

Code	Abdomen (%)	Head & Neck (%)	Cardiac (%)	Musculoskel. (%)	Neurol. (%)	Thoracic (%)	Vascular (%)	Initial cluster	Euclidean distance from centroid	Final cluster	Euclidean distance from centroid
M1	87	0	0	0	9	4	0	1	5.4	1	14.7
M2	70	1	0	1	17	10	1	1	24.7	1	7.5
M3	95	0	0	0	0	0	5	1	8.4	1	25.6
M4	100	0	0	0	0	0	0	1	11.3	1	30.1
M5	100	0	0	0	0	0	0	1	11.3	1	30.1
M6	23	1	0	38	12	26	0	2	26.9	2	25.8
M7	11	1	0	84	0	4	0	2	26.9	2	58.3
M8	36	4	0	2	38	18	2	3	10.3	3	15.2
M9	34	1	0	5	28	32	0	3	18.8	3	21.0
M10	26	3	0	11	36	23	1	3	14.1	3	10.2
M11	22	20	0	8	34	15	1	3	16.2	3	18.5
M12	21	4	0	6	31	36	2	3	23.0	3	17.7
M13	18	6	0	2	27	45	2	3	32.1	3	27.6
M14	14	43	0	7	24	10	2	3	40.0	2	37.1
M15	47	38	0	0	15	0	0	3	41.2	2	44.8
M16	4	4	0	6	72	7	7	3	50.1	3	40.1
M17	32	1	0	1	56	8	2	3	27.5	3	24.4
M18	9	2	0	2	34	9	44	3	45.3	3	42.1
M19	52	7	0	2	29	8	2	3	23.0	1	28.2
M20	54	1	0	1	23	20	1	3	26.3	1	26.1
M21	54	2	0	2	28	9	5	3	25.2	1	25.5
M22	52	1	0	6	3	14	24	3	40.5	1	31.9
M23	1	0	20	0	1	75	3	4	22.8	4	22.8
M24	8	2	0	1	21	67	1	4	26.4	4	26.4
M25	8	1	0	0	11	80	0	4	11.0	4	11.0
M26	4	0	0	0	22	74	0	4	21.3	4	21.3
M27	0	0	0	0	0	100	0	4	13.9	4	13.9
M28	0	0	0	0	0	100	0	4	13.9	4	13.9
M29	2	0	0	0	0	98	0	4	12.0	4	12.0
M30	2	0	0	0	0	98	0	4	12.0	4	12.0
M31	0	0	0	0	0	100	0	4	13.9	4	13.9

As previously mentioned, nine additional radiologists (coded M32 to M40) were assigned to clusters a posteriori, based on expert opinion from RD managers. Most of them were assigned to cluster 2 (M32 to M37), while the others were assigned to cluster 3 (M38 to M40).

The radiologists' working scale was used to define the minimum number of workstations to be included in each working cell. That number resulted smaller than the total number of radiologists assigned to each cell, due to the fact that most radiologists are part-time workers.

Relationship Diagram

Figure 2 shows the resulting relationship diagram for the RD reporting area and its surroundings; 13 sectors were included

in the diagram, as follows: entrance/reception, administrative area, administrative staff and radiologists relax areas, meeting room, reporting room for emergencies (noisy), male and female restrooms, locker room, and 4 reporting working cells (quiet).

Layout Alternatives

Initially, three layout alternatives were generated and presented to the RD staff and hospital architects in a meeting. New demands and elements to be considered in the layout were gathered in the meeting, resulting in five additional layout alternatives. We thus concluded SLP's Research phase with a total of eight layout proposals, some of which are presented next.

Fig. 2 Interrelations for the radiology division sectors involved in this study

Figure 3 shows the positioning of working cells (corresponding to clusters) in the first layout presented to stakeholders. The main concern here was to segregate quiet and noisy areas; however, the suboptimal use of space in the proposal was clear: there was a large unnecessary circulation area between sectors 3, 5, 6, and 9, and an excessive number of corridors separating working cells. Other negative points were (i) insufficient number of workstations in working cells; (ii) restrooms separated from the locker room; (iii) two separate entries for staff and clients, wasting space; (iv) flow of clients through the administrative area; (v) nonlinearity of flows (both clients and staff). Although respecting proximity preferences in Fig. 2, the layout presented drawbacks and, therefore, opportunities for improvement.

The eighth layout proposition is displayed in Fig. 4. Once again, proximity preferences were respected; however, a large number of improvements were incorporated if compared to the first layout, which are discussed in the next section. The final layout proposal (Fig. 5) was generated improving on the layout in Fig. 4, incorporating changes proposed by the stakeholders, and allowing a better use of the available space and dimensioning working cells to the final number of radiologists assigned to them in different work shifts. It is worth noting that the use of a single central corridor for circulation, results in better use of space and linearization of people and information flows. The central corridor connects with all reporting working cells and all main sectors.

Considerations on the Selected Layout

Figure 5 shows the redesigned view of proposition 8 (Fig. 4) obtained using SolidWorks™ software (*Dassault Systemes, SolidWorks Corporation, USA*), with the positioning of workstations. A greater number of stations were added in working cells 12 and 13 if compared to proposition 8, and a space was reserved for the HVAC equipment (area 14) in the quiet area. Workstations in the administrative wing were better organized. A partition in the urgency room (area 4) was also added, to isolate radiologist interns with research assignments.

Regarding other proposals (not shown here) and the original layout of the RD (Fig. 1), the proposition in Fig. 5 displays a better use of space and corridors. The arrow indicates the single entry to the service, which gives direct access to the reception. On the left side of the reception, the administrative room was positioned; on the right side, there is the administrative relax area. A door separates the reception from a central corridor which gives access to both noisy and quiet areas. In the noisy area, there is a meeting room for case discussions, positioned in front of the urgency reporting room, where a group of radiologists will be available to answer technical questions from the operational radiology personnel, and for case discussions with the clinical staff. At the end of the noisy area, there are restrooms, locker rooms, and the relax area for radiologists.

Reporting cells, defined through cluster analysis, were positioned in the quiet area. Based on the number of radiologists per shift, two larger rooms were dedicated to the abdominal

Fig. 3 First layout proposal

PROPOSAL 1**SUBTITLE**

- 1-ENTRANCE/RECEPTION
- 2-ADMINISTRATIVE AREA
- 3-URGENCY ROOM
- 4-ADMINISTRATIVE RELAX AREA
- 5-LOCKER ROOM
- 6-RADIOLOGISTS RELAX AREA
- 7-MEETING ROOM
- 8-MALE RESTROOM
- 9-FEMALE RESTROOM
- 10-ABDOMINAL
- 11-THORACIC/CARDIAC
- 12-NEUROLOGIC/VASCULAR/HEAD & NECK
- 13-MUSCULOSKELETAL

(cluster 1) and thoracic/cardiac (cluster 4) subspecialties, and two smaller rooms were dedicated to the musculoskeletal (cluster 2) and neurologic/vascular/head & neck (cluster 3) subspecialties.

Discussion

In this study, we presented two important contributions to the literature on layout studies in healthcare systems. The first was the use of cluster analysis as a preliminary step to SLP, aimed at organizing radiologists in working cells to be eventually positioned in the layout using SLP tools. The application of cluster analysis to identify working cells joining individuals with similar abilities in a healthcare context has no parallel in the literature, as well as its use as supporting tool to SLP. The second contribution is the presentation of a case study analyzing an RD layout problem. To the best of our knowledge, both constitute innovative contributions to the scarce literature on layout studies applied to healthcare systems.

In most studies on the subject of healthcare systems design [18, 22–25], the layout problem was characterized by the flow of patients and staff, or the materials and equipment used in healthcare. In addition to the theoretical contributions listed

above, the work also brings a practical contribution to improve the working environment and provide a better flow of information in the RD of a reference hospital.

Throughout the study, the methodology highlighted the importance of involving stakeholders in decision-making, in each stage of the SLP method, addressing their considerations before moving to the next method step. Inputs and opinions from different experts were taken into consideration when planning the layout of the reporting area. In general, the proposed method provided a greater involvement and participation of different groups to achieve a common goal.

Particularly, the benefits of defining areas with a high degree of interaction and positioning them in proper proximity have the potential to limit the transit of people, which brings noise and disruptions in the reporting activity, while improving the flow of information. Additionally, the clear separation of noisy and quiet areas limits unplanned interruptions and enhances the exchange of knowledge and information inside cells, joining radiologists with the same expertise (subspecialty) in the same space.

In summary, we described a step-by-step method to plan an RD reporting layout. The effectiveness of benefits derived from such approach on radiology reporting quality and turnaround times should be the subject of further research.

Fig. 4 Eighth layout proposal

PROPOSAL 8**SUBTITLE**

- 1-ENTRANCE/RECEPTION
- 2-ADMINISTRATIVE AREA
- 3-ADMINISTRATIVE RELAX AREA
- 4-URGENCY ROOM
- 5- MEETING ROOM
- 6-FEMALE RESTROOM
- 7-MALE RESTROOM
- 8-LOCKER ROOM
- 9-RADIOLOGISTS RELAX AREA
- 10-ABDOMINAL
- 11-THORACIC/CARDIAC
- 12-NEUROLOGIC/VASCULAR/HEAD & NECK
- 13-MUSCULOSKELETAL

Fig. 5 Final layout proposal in SolidWorks

SELECTED LAYOUT**SUBTITLE**

- 1-ENTRANCE/RECEPTION
- 2-ADMINISTRATIVE AREA
- 3-ADMINISTRATIVE RELAX AREA
- 4-URGENCY ROOM
- 5-MEETING ROOM
- 6-FEMALE RESTROOM
- 7-MALE RESTROOM
- 8-LOCKER ROOM
- 9-RADIOLOGISTS RELAX AREA
- 10-ABDOMINAL
- 11-THORACIC/CARDIAC
- 12-NEUROLOGIC/VASCULAR/HEAD & NECK
- 13- MUSCULOSKELETAL
- 14-HVAC EQUIPMENT

Conclusions

This paper presented a contextualization of the importance of layout planning in health care. Such contextualization sought to make a layout planning in radiologist's reporting area. The analysis was divided into two levels: micro and macro. At the micro level, the cluster analysis was applied to find the ideal number of clusters of medical specialists. At the macro level, the SLP steps were applied to arrive at layout alternatives and select the best one for implementation.

Throughout the research, the methodology evidenced the importance of stakeholder participation in each stage of the SLP. Comments and opinions from different experts were taken into consideration when planning the layout of the reporting area. In general, the methodology provided a greater commitment and participation of different individuals to reach a common goal.

After the implementation of the proposal, it would be interesting to carry out an evaluation of the layout performance proposed in this paper. This evaluation would make it possible to compare and verify the efficacy of the new radiology reporting area in relation to the previous one. Thus, it would be possible to find new noises in the new layout and optimize it through SLP.

Acknowledgments This work was made possible by the sponsorship of CNPq (Conselho Nacional de Desenvolvimento Científico e Tecnológico), CAPES (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior), FIPE (Fundação Instituto de Pesquisas Econômicas), and Hospital de Clínicas de Porto Alegre, Brazil.

Compliance with Ethical Standards The HCPA's Ethical Committee has approved this study, and authors have complied with the recommendations of the Declaration of Helsinki.

References

- Bhargavan M, Kaye AH, Forman HP, Sunshine JH: Workload of radiologists in United States in 2006–2007 and trends since 1991–1992. *Radiology*. 252(2):458–467, 2009. <https://doi.org/10.1148/radiol.2522081895>
- Duszak, Jr R, Muroff LR: Measuring and Managing Radiologist Productivity, Part 1: Clinical Metrics and Benchmarks. *Journal of the American College of Radiology*. 7(6):452–458, 2010. <https://doi.org/10.1016/j.jacr.2010.01.026>
- MacDonald SL, Cowan IA, Floyd R, Mackintosh S, Graham R, Jenkins E et al.: Measuring and managing radiologist workload: application of lean and constraint theories and production planning principles to planning radiology services in a major tertiary hospital. *Journal of medical imaging and radiation oncology*. 57(5):544–550, 2013. <https://doi.org/10.1111/1754-9485.12090>
- Ondategui-Parra S, Gill IE, Bhagwat JG, Intrieri LA, Gogate A, Zou KH et al.: Clinical operations management in radiology. *Journal of the American College of Radiology : JACR*. 1(9):632–640, 2004. <https://doi.org/10.1016/j.jacr.2004.04.015>
- Dora J, Torres F, Gerchman M, Fogliatto F: Development of a local relative value unit to measure radiologists' computed tomography reporting workload. *Journal of medical imaging and radiation oncology*, 2016. <https://doi.org/10.1111/1754-9485.12492>
- Crabbe JP, Frank CL, Nye WW: Improving report turnaround time: an integrated method using data from a radiology information system. *AJR American journal of roentgenology*. 163(6):1503–1507, 1994. <https://doi.org/10.2214/ajr.163.6.7992756>
- Goyal N, Jain N, Rachapalli V: Ergonomics in radiology. *Clinical Radiology*. 64(2):119–126, 2009. <https://doi.org/10.1016/j.crad.2008.08.003>
- Gupta V. Radiodiagnosis and Imaging Services. In: Goel SD, editor. *Textbook of Hospital Administration*. 1 ed. India: Elsevier India; 2014.
- Tellioglu H, Wagner I: Work Practices Surrounding PACS: The Politics of Space in Hospitals. *Computer Supported Cooperative Work (CSCW)*. 10(2):163–188, 2001. <https://doi.org/10.1023/a:1011298824442>
- Kulkarni MH, Bhatwadekar SG, Thakur HM: A literature review of facility planning and plant layouts. *International Journal of Engineering Sciences & Research Technology*. 4(3):35–42, 2015
- Shayan E, Chittilappilly A: Genetic algorithm for facilities layout problems based on slicing tree structure. *International Journal of Production Research*. 42(19):4055–4067, 2004. <https://doi.org/10.1080/00207540410001716471>
- Arnolds I, Nickel S: Layout planning problems in health care. In: Eiselt AH, Marianov V eds. *Applications of location analysis*. Cham: Springer International Publishing, 2015, p 109–52. https://doi.org/10.1007/978-3-319-20282-2_5
- Tompkins JA, White JA, Bozer YA, Tanchoco JMA: *Facilities planning*. 4 ed: Wiley, 2010
- Yang T, Su CT, Hsu YR: Systematic layout planning: a study on semiconductor wafer fabrication facilities. *International Journal of Operations & Production Management*. 20(11):1359–1371, 2000. <https://doi.org/10.1108/01443570010348299>
- Gupta K, Gupta SK, Kant S, Chandrashekhar R, Satpathy S: *Modern trends in planning and designing of hospitals: Principles and practice*: Jaypee Brothers Publishers, 2007.
- Tortorella GL, Fogliatto FS: Planejamento sistemático de layout com apoio de análise de decisão multicritério. *Production*. 18: 609–624, 2008. <https://doi.org/10.1590/S0103-65132008000300015>
- Muther R: Planejamento do layout: sistema SLP. E. Blucher, 1978
- Joseph A, Rashid M: The architecture of safety: hospital design. *Current opinion in critical care*. 13(6):714–719, 2007. <https://doi.org/10.1097/MCC.0b013e3282f1be6e>
- Suresh NC, Kay JM: *Group technology and cellular manufacturing: A State-of-the-Art synthesis of research and practice*: Springer US, 2012
- Lee Q: Projeto de instalações e do local de trabalho: IMAM, 1998
- Muther R, Wheeler JD. Planejamento Sistemático e Simplificado de Layout: Sistema SLP. São Paulo: IMAM; 2000.
- Lin Q-L, Liu H-C, Wang D-J, Liu L: Integrating systematic layout planning with fuzzy constraint theory to design and optimize the facility layout for operating theatre in hospitals. *Journal of Intelligent Manufacturing*. 26(1):87–95, 2015. <https://doi.org/10.1007/s10845-013-0764-8>
- Hua Y, Becker F, Wurmser T, Bliss-Holtz J, Hedges C: Effects of nursing unit spatial layout on nursing team communication patterns, quality of care, and patient safety. *Herd*. 6(1):8–38, 2012. <https://doi.org/10.1177/193758671200600102>
- Rashid M: Research on nursing unit layouts: an integrative review. *Facilities*. 33(9/10):631–695, 2015. <https://doi.org/10.1108/F-01-2014-0009>
- Brogmus G, Leone W, Butler L, Hernandez E. Best practices in OR suite layout and equipment choices to reduce slips, trips, and falls. *AORN journal*. 2007;86(3):384–94; quiz 95-8. <https://doi.org/10.1016/j.aorn.2007.06.00>