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Development of assistive robotic beds for hospitals

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RESUMEN

En este documento se propone una metodología para la definición de proyectos en el área de cama robótica que responda a las necesidades reales de los hospitales públicos de Latinoamérica. La importancia de esta metodología depende de que los proyectos son definidos para responder a las necesidades reales en los hospitales. Esta metodología considera siete pasos: prediagnóstico, diagnóstico, valoración de factibilidad técnica, valoración de factibilidad económica, valoración de factibilidad operacional, análisis de origen de factibilidad y análisis de origen de viabilidad. El método de diagnóstico (MD) auxilia en el desarrollo de una cama robótica analizando su impacto en un medio ambiente hospitalario, y desde ahí, teniendo un impacto directo en las innovaciones de los nuevos robots con las nuevas aplicaciones, especialmente con los pacientes ancianos y minusválidos. Sin embargo, el MD puede ser aplicado en otros campos. Por estas razones, esta metodología es muy conveniente para instituciones o compañías privadas interesadas en desarrollar aparatos robóticos. La falta de esta metodología, como la que se presenta, generalmente muestra la falla en la implementación técnica, así como en los aspectos comerciales que desde el inicio del proyecto puede ser una pérdida de recursos más que una inversión.

Palabras clave. *Camas robóticas, factibilidad operacional, impacto social.*

ABSTRACT

In this paper we introduce a methodology for the definition of projects in the area of robotic beds that respond to the real needs of public hospitals in Latin-American. The importance of this methodology relies on the fact that the projects are defined according to it respond to real needs in hospitals. This methodology considers seven steps: pre-diagnosis, diagnosis, technical feasibility assessment, economic feasibility assessment, operational feasibility assessment, feasibility matrix analysis and viability matrix analysis. The diagnostic method (DM) helps with the development of a robotic bed by analyzing its impact in a hospital environment and hence by having a direct impact in the innovations of new robots with new applications mainly for elderly and disabled patients. The DM can be applied in other fields. For these reasons this methodology is very convenient to institutions or private companies interested in developing assistive devices. The lack of a methodology like the one presented, usually leads to failure in the technical implementation, as well as in the commercial aspects since the beginning of the project may be a waste of resources rather than an investment.

Key words. *Robotic beds, operational feasibility, social impact.*

INTRODUCTION

Robotic beds (RB) is the area of robotics that deals with the design and construction of devices that interact with individuals to enhance or improve their impairments when they see their mobility capacities diminished when they have lost a limb. It is a growing area of research with potential benefits for the elderly, education,

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and rehabilitation and for people with social and cognitive disorders.[1-3] Also, the obesity has become an important problem in Latin America with the increasing number of obese people. Each time it is more necessary to invest in special beds for these kinds of patients in hospitals. Ulcers by pressure (UBP) are injuries of ischemic origin located on the skin or underlying tissue. They are a special kind of lesion cause by bad irrigation blood and nutrition tissue slide, and produced by the combined action of extrinsic factors, which are high pressure and friction, being determinant the relation pressure/time. There is a trend expected from the service of robots market which is equivalent to 51 MM Dls (billion dollars) by 2025. The evaluation of assistive beds (RB) proposals presents novel challenges. The use of a bed for a health assistive task has several benefits and ethical implications. Many questions have to be answered to decide if a RB is effective in a given application domain. There exist many methods for evaluating the factors involved in the design and application of a RB. Psychological, anthropological, medical, as well as human-robot interaction benchmarks are proposed as reference measures for assessing the performance of a given RB and for evaluating its impact in the user's life and in the society in general.[1,4,5] Most of the time none of the factors mentioned above is used to develop a technology project in Latin America for commercial purposes. The rehabilitation bed as a tool in Latin America is just beginning progress unlike countries such as Switzerland, Holland, England, Germany and the U.S. The technology promises to be the mainspring of industry in Latin America if properly supported. This implies a high risk since technology projects should impact on society, but without a diagnostic method to evaluate the viability of the project it is very difficult to assess this impact. In Latin America it is needed to link companies and universities to develop this area; it will be essential to know which are the niche markets and their specific needs but this depends on how well is the marketing analysis with users.

A diagnosis methodology (DM) for technology projects development refers to the framework that is used to assess the feasibility of the development of a device or system by analyzing its impact in a specific environment. Once it decided that it is a feasible project then it can be developed.

A wide variety of such frameworks have evolved over the years, each with its own recognized strengths and weaknesses.

One diagnosis development methodology is not necessarily suitable for all projects. Each of the available methodologies is best suited to specific kinds of projects, based on various technical, organizational, project and team considerations. In our methodology presented here, we have considered each of the major prescribed methodologies in context with business, applications, organization, and technical environments. New technologies and advances in robotics enable the design of assistive robots for the disabled, the elderly and the sick. RB and the associated technology can also be used to support hospital services. The final goal is to assure the disabled a greater degree of autonomy in his surrounding environment, and ease the task of the assistive personnel dealing with the user.

RB technology globally develops with great momentum and many social problems are being solved using it. Latin-American industry must take the necessary steps to update its industrial machinery in order to improve the quality of its products. The RB projects must also include the education of personnel in this area of knowledge. Going in this direction, assistive robotic projects developments should incorporate diagnosis methodologies. The evaluation of different RB projects is performed via benchmarks established for each need that has to be satisfied by these robots.[3,5] However, in Latin America this is often underestimated in academia and in the business sectors since specialized methodologies are lacking in the area of technological development.

Our methodology here presented helps to assess the feasibility of a given project in RB. Our proposal emerges in order to apply RB in our country and in Latin America's health services, according to the needs of a specific population, allowing lower costs and having as a plus the generation of employment.

The complexity degree in the proposition of a viable project for building an RB is reflected in the studies that have to be carried out studying the statistics that enable to perform operational, economic, and health analysis of a given situation, and to assess the social impact as well as the feasibility analysis of a given project. If the specific needs for the construction of an RB device are not well established, any building project is bound to failure.

BACKGROUND AND RELATED WORK

It is necessary to define the range of roles that a robot can play in the life of a human user. It is also important to point out that an RB must consider aspects such a safety, scalability, autonomy, imitation, privacy, social success and its impact in the care of the users, caregivers and the life of the user in general. Robotic researches have studied the advantages and challenges of the use of robots to assist the elderly at home or in hospitals. They work to automate some physical tasks that an elderly person may not be able to do, such as making-up, brushing their teeth, getting in and out of bed, getting in and out of a wheelchair or adjusting the position of a bed for maximum comfort. These robots can be used as part of a ubiquitous computing system which combines cameras and other sensors and computer controlled appliances (such as light switches, doors and televisions), or as a single unit. RB systems have also been used as companion robots in the public areas of nursing homes, aimed to increase the socialization between residents.[2]

Current research in robotics assumes safety as "low level" priority and considers the evaluation of a project from an ethical point of view. While no specific guidelines have yet been established for the evaluation of robotic projects, active discussions have begun in the field. The study of the relation between humans and interactive robots has been addressed by researches by asking residents of a nursing home to care for a robot baby. The interaction between humans and assistive robots gives rise to interesting social side effects with ethical ramifications.[2,5] Previous benchmarks addressed the differences between machines built to serve a human masters and those built to act with autonomy and to cooperate or assist human beings.[2]

No doubt, robotics has grown in scope not only in industry but in areas such as medicine and health, agriculture, transportation and education, among others. This growth and marketing is shown in the case of developing training materials such as Lego Mindstorms. At the national level, in Mexico there are organized entertainment events like Roboshow, and robot war that although don't present scientific development of robotics, at least attempted to stimulate an interest in students. So to succeed fully consolidate laboratories devoted to research and development of robotics in Mexico it should have the interest in learning to work with different areas of knowledge and insist on creating links between industry and academia.

Generally this is a problem that is certainly not easy to solve and requires first to try methodologies that allow the detection of needs that can be solved by a robot and then its development in a timely manner. Without doubt, the study and interest in robots has grown not only academically, but has managed a major impact on the industry and now as a big business. No wonder that the development of robots has been strongly linked to the development of computing and electronics itself. Thus, several years ago it was impossible to think of robotics projects at universities, research centers or institutions with limited financial and human resources in developing countries.

Undoubtedly the field of robotics still has a long way in Mexico. The application and fears that have arised with the robots is definitely a huge factor advertising and also of interest.

Our approach aims to provide a contribution to the orderly development of assistive robotics projects in Mexico today.

RESEARCH APPROACH IN METHODOLOGY DESIGN

The effect of assistive devices on human psychology

There have been recent discussions about the benefits of using RB. Some clinical studies have made it clear, by using quality of life (QOL) model of Lorentsen,[1,3,6] that RB has a great impact in the physical health, the daily life activity, the social and eventually the spiritual life of the user by easing his/her daily life activities and the physical burden on caregivers. The application of the QOL to some clinical studies have made it clear that by easing the everyday life activities of severely disabled users and by easing the physical burden that they are for caregivers, RB has a great physical, social and eventually spiritual impact in the everyday life of these people. These factors should be taken into account when the evaluation of a project is performed. Reports exists on why RB is not being used in the clinical field. The acceptance of disability itself is one of the causes to reject RB treatment. Rosalind, *et al.* describes how physiological and social care became necessary as therapists introduced RB to users in the 1980's. In the literature, Krueger's disability acceptance model explains the shock that arises when the user's disability is confronted with the expectations of recovery, and the confusion that arises when they try to adapt to the use of a wheelchair.[1,4,5]

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RB helps people live their lives in general. In our country there are many areas of opportunity where assistive robots can be employed. Considering that in a few years we will have a large elderly population, the application of RB will be of great impact. It is difficult to make a difference between the elderly and people with disabilities in the context of RB benefits. We simply consider that the functions of an assistive device help both of them without great differences. We have developed the diagnosis methodology in collaboration with the medical staff of the Hospital Juárez de México (HJM). The goal is to provide a methodology to assess if a specific assistive robot should be built or just analyzed as a technical proposal. This methodology allows having a more extended view about the technical proposal.

We have applied our methodology for the first time in the HJM environment.

THE PROPOSED METHODOLOGY

Developmental requirements

We developed our methodology based on the concepts outlined above. The usual cause of failure in the operational phase of RB projects is how their need and applications were determined. An assistive robot should be needed or it will never be used.

The cause of the psychological conflict of the elderly or disabled people who have to use an assistive robot can be clarified by a qualitative research approach. The introduction of some activities in their lives is advisable in order to devise a solution to the existing conflicts. Activities such as the following are proposed:

- Maintenance of the body functioning: maintenance of muscles and joint motion.
- Expansion of the mobility activities: expand the mobility activity related to everyday activities.
- Maintenance of natural body appearance: maintenance of a natural body motion.

Maintaining the appearance of being able to move by enabling natural motion, speeding up the body movements and making the body movements more comfortable, are part of the concept.

The targets for these people are the ability to move by their own, but not quickly, the ability to maintain or expand their mobility area, and the ability to give the general impression of being able to move.

Requirements of the components

To decide upon a concrete mechanical requirement from those listed above, we initially categorized the relationship between the human bodily phase and the mechanical phase, both shown in figure 1. Human functions have three factors to consider: the sensory system, the central nervous system and the physical function considered. These factors are integrated in the body movement and the body appearance is dictated by the movement itself.

Likewise, the mechanical system consists of three main factors: the operative system, the control system, and the mechanical function. These three factors are integrated in the mechanical design. The interfaces that connect the human and the mechanical function are the human sensory receptor to recognize the mechanical function (behavior) and the operating system to use the physical function. Therefore, to meet the developmental requirement by amplifying the results of the system's movement for the operation of one's own body movement, is one solution. Based on an example of these solutions, the designer should propose a new mobility aid that must be analyzed by the medical staff together with the technical team in order to identify the principal need required in HJM. Any proposal should be designed to meet the following three requirements: the maintenance of body functioning; the extension of the mobility; and the maintenance of a natural gait. The target users have the following characteristics: the ability to move by themselves; the motivation to maintain or expand the geographical area in which they move; and the wish to appear as though they move naturally.

Prototype construction

Once we identify a need in HJM, a detailed technical proposal should be done in order to construct each suggested prototype. This implies the determination of a working plan, developing times, costs, deadlines, the identification of prices, suppliers, materials, technical experts, required software, etc.

Proposal of a methodology for the definition of RB projects

In this section a methodology that can be a guide to the identification of the major needs in a hospital like HJM is proposed. This proposal must take into account all the topics mentioned in former paragraphs. This methodology must minimize the risk of failure of any project in assistive robotics. Our methodology consists of the following stages:

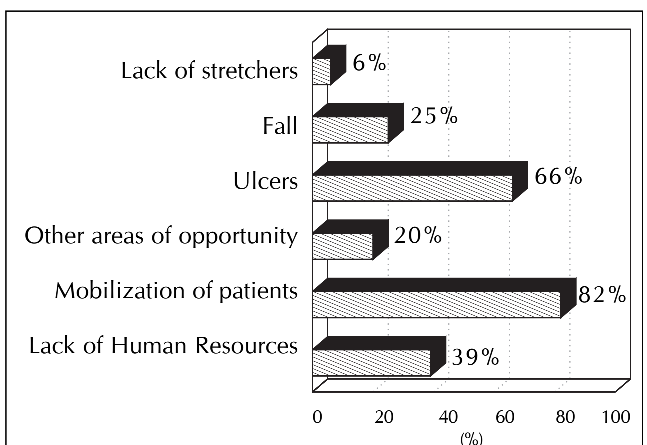

Figure 1. *Areas of opportunity. Staff surveyed (global): 285.*

- **First stage: Pre-diagnosis.** As an initial approach, this stage considers visits to the specific areas of interest previously defined, interviews to their staffs, and where allowed, the filming of videos and the taking of pictures of the areas, the filling in of general questionnaires aimed to survey their needs in the areas of RB. The results of this first approach allow the knowledge of the main services offered by each area and the resources they have in terms of physical infrastructure, productivity, offered services, required services, robotic technology employed and the RB technology needed. The general questionnaires created for this stage are filled in by heads of departments and the employees of the selected areas to initiate the diagnosis stage.
- **Second stage: Diagnosis.** This stage consists in the feedback of information obtained in the first stage in order to expand the results found in the pre-diagnosis stage. This stage also considers the design of a specific questionnaire aimed to each area of interest focusing on the determination of the benefits that automation of certain of their activities would bring to them. The activities considered to be improved by automation consist of the following areas:

  a) Medical support.
  b) Nursing support.
  c) Educational support.
  d) Benefit to users.
  e) Administrative support.

  This survey is helpful to determine the needs of the servicing areas of the hospital and the feasibility of the proposed projects to satisfy them by employing RB. At this stage thirty five feasible projects were identified in HJM in the area of RB.
- **Third stage: Technical feasibility assessment.** Once the robotics projects have been defined in the previous stage, we proceed to perform their technical feasibility assessment. The projects were classified as welfare and non-welfare robotic projects. The technical as well as the technological feasibility of each project was assessed according to their construction difficulty. This assessment took the elaboration of thirty five feasibility matrices corresponding to the thirty five projects defined in HJM which contrast the characteristics of each of the projects. These feasibility matrices cover aspects as:

  a) Materials and parts for mechanical processing, computing and electronics.
  b) Tools for the implementation of the project.
  c) Human resources.
  d) Time planning of the project (see tables 1 and 2 that show the required information in this stage).

- **Fourth stage: Economic feasibility assessment.** Having assessed the RB projects whose technical characteristics make them feasible to be built, they are subjected in a similar way to an economic evaluation that includes cost and manufacturing difficulties determination, which among other aspects include: the device description, the cost, the operational characteristics, the materials involved, the dimensions of the prototype, problems associated with the availability of resources, difficulties associated with the construction of each project, their costs and the ranges of their fluctuations. This economic evaluation includes aspects such as benchmarking, cost of the electronic, electrical as well as the mechanical components, the cost of their assembly and the cost of the parts procurement, etc. At this stage, six matrices were developed for the assistive robotics projects (see table 3 that show required data for this assessment).
- **Fifth stage: Operational feasibility assessment.** We named this stage operational assessment because

Table 1. Materials for mechanical, computational and electronic implementation.

Category	Type/technology	Amount	Dealer or manufacturer	Total cost	Delivery time	Comments

Table 2. Tools for project implementation.

Category	Type	Amount	Dealer or manufacturer	Unit cost	Total cost	Delivery time	Comments
Mechanical							
Calculation							
Electronic							
Specialized							

Table 3. Economic evaluation matrix. Summary.

Project parameter	Bed of multiple positions	Smart mattress	Patient transport device	Exo-skeleton	Positions table scan	Stretcher bed patient transporter
Competition analysis						
Local suppliers						
Manufacturers						
Origin						
Cost						
Operational features						
Website						
Materials						

we consider those special aspects that deal with the operation of general assistive robots and in particular medical robots in a hospital premises or the doctor's office. These aspects include also the relationship between the RB projects and any robot in particular with different people like the healthy, the ill, the elderly, paramedics and nurses and medical personnel in general. These relationships should make us think about the effectiveness of a given project and the limits we must impose on the RB, as far as the decision making processes is concerned because at the end, It is the medical personnel and in particular the doctors, the ones responsible for the decisions taken. At this stage thirty five operational matrices were produced which are related to analyzed different projects in the HJM. At this stage the following aspects are considered: medical robot effectiveness (the determination of what extent a robot produces the desired practical effects), reliability (robustness, security, interoperability and ease of repairmen and maintenance), ease of use (the design of man-machines interfaces and the necessary training to the personnel involved).

It is also important to count on the acceptability of the staff in general. This technology should not be considered by the employees of the hospital as a tool to make them redundant. So, it is advisable to consider that any project should pay attention to:

a) Social and institutional support needed by most of the successful projects.
b) The appointment by the medical staff of a leader chosen from inside their group to lead the project and to transmit to the whole organization an overview of the objectives, priorities and needs of the team.
c) The rectification of any deficiency in the conduction of the project detected by the opportune feedback of the users' opinion.

- **Sixth stage: Feasibility analysis matrix.** It is defined as the availability of the necessary resources to carry out the objectives and the target set. The matrix is derived from the analysis of the previously prepared matrices that include the objectives, the scope and the restrictions of the robotic systems. This analysis includes the technical feasibility analysis (evaluate if the necessary technology to develop the system is available), the economic feasibility analysis (benefit-cost, raw materials, etc.), the operational or organizational feasibility (assessment of the possibilities of being able to operate the system in the organization).
- **Seventh stage: Viability matrix.** It is known as the study viability analysis that tries to predict the eventual success or failure of a project. To achieve this, we start from empirical data, (that can be tested) data that are accessed through various types of research (surveys, interviews with experts or opinion leaders, statistics, etc.). The viability analysis is developed by the government or corporate level. This is a useful resource prior to the initiation of a work or the launching of a new product, thus minimizing the error margin since all the circumstances related to the projects are studied. In this methodology, we constructed a matrix with these factors which has three colors to represent heavier relevant information to support or discard easily each project. Also it shows technical, economic and operational aspects so that together define the viability of each project (Table 4).

Using this methodology considers the following factors:

a) **Impact on the clinical process:** Measures the effects of the introduction of technology in the clinical process of care vs. alternative systems.
b) **Impact on the health of the patient:** It refers to the effects of the introduction of technology in the patient's health vs. an alternative system.

Table 4. Viability analysis matrix.

Evaluation criteria	Bed of positions	Smart mattress	Transport device: Stretcher wheelchair	Exo-skeletons	Positions table of exploration	Crane
Social impact						
Number of beneficiaries	10	9	9	10	10	10
Areas benefited	10	10	10	9	10	10
Institutional viability	10	9	10	10	10	10
Operational impact						
Acceptability by staff	10	10	8	9	9	10
Expected effectiveness	10	9	9	9	9	10
Ease of use	9	10	10	9	10	10
Technical Aspects						
Technological innovation	10	10	9	7	9	10
Technical feasibility	10	9	9	8	10	9
Availability of suppliers	10	9	10	8	9	8

c) **Impact on the accessibility:** Measures the greater or lesser access to health care provided by the introduced technology front.
d) **Economic impact:** refers to the costs of implementing the new technology for the patient and the costs of health insurance with private or public companies, or the cost charged to society in general.
e) Impact on the acceptability of the health care system.

Also, the following aspects are considered by our methodology: institutional viability, impact on the organization structure, the acceptability by patients, economic viability, benefit areas, hospital statistics, expected impact on hospital society, social profit, economic benefits, legal and regulatory cost/income expected, organizational impact, and innovation.

RESULTS

In agreement with the HJM's administration the following areas were selected in order to apply our methodology.

- Intensive Care Service.
- Emergency Department.
- Endoscopy Service.
- Operating room services and general surgery.
- Service and Ostomy wound clinic.
- Hospitalization.
- Rehabilitation service.

This methodology implies the making of surveys, personal interviews as well as the review of reference material. There are specific sets of questions per stage, i.e. a questionnaire for the pre-diagnosis, the diagnosis, the technical evaluation, the operational evaluation the technical feasibility matrices, the operational feasibility matrices stages. There are also specific questionnaires for leaders, executives (doctors, nurses), managers, physicians, nurses and doctors; this implies visits to the hospital services. Once the assistive projects have been defined, it is necessary to perform benchmarking to assess costs, technology innovation, technical and operational characteristics, providers, the country of origin of the products as well as the manufactures and materials involved in the development of the project. These data is useful in order to know if a technical proposal can compete in the global market or not.

To make a technical proposal, documentary research of technical publications, scientific magazines and websites is compulsory. A review of the possible robotic projects to develop is also necessary as well as the generation of all the documents to describe each project. Other important details comprise visits to hospitals, to manufacturers, and to suppliers of materials and electronic parts, to providers and electronic manufacturers and to the technical team of the hospital where the project is going to be developed. We show in tables 5 and 6 some of the medical statistical information we analyzed from HJM's information that was obtained from our methodology's application.

The application of the proposed methodology gave the following results. The tables shown are the medical statistics

Table 5. Number of hospital beds. Division of surgery.

Service	Beds (n)	Expenses	Expenses / Beds
Division of Surgery			
Cardiovascular Surgery	6	230	38
General Surgery	47	2,437	52
Maxilo/facial Surgery	3	155	52
Plastic Surgery	4	275	69
Chest Surgery	2	25	13
Ophthalmology	4	334	84
Oncology	37	2,294	62
Orthopedic	32	813	25
Otorrinolaringology	6	518	86
Urology	10	772	77
Neurosurgery	15	570	38
Subtotal	166	8,423	**596**

Table 6. Total hospital beds. Hospital Juárez de México.

	Beds (n)	Expenses	Expenses / Beds
General total	394	18,619	47

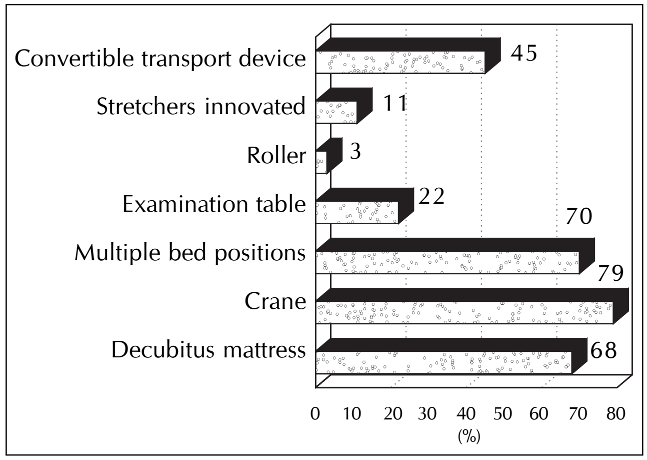

Figure 2. *Technological proposals. Staff surveyed (global): 285.*

of HJM. These data are important because show the behavior of the patient group in the hospital. Consideration of these data is useful to assess the technical viability of a proposed project.

In the study case of HJM, the methodology application considered 105 doctors (there are 300 doctors in the hospital), 41 bearers (there are 80 bearers in the hospital), 139 nurses (there are 800 nurses in the hospital) and about 250 patients.

This information gives the real situation about the perception of the medical experts of the hospital. The feedback from the medical staff is very important because it guides the technical proposal in terms of requirements.

At the same time, patients were considered only for the determination of the design details of the assistive robot but the medical staff was considered for knowing the most important needs in the hospital.

Figure 1 shows the main areas of opportunity where an assistive robotic proposal should be done. The set of requirements of the hospital is clear. Figure 2 shows the main accepted assistive robotic proposals by the medical staff in HJM.

Figures 1 and 2 show the obtained results, in this case, it is clear that HJM offers an important area of opportunity in the context of mobility for the elderly and disabled patients. According to the results obtained using the proposed methodology, it can be said that the HJM needs assistive proposals in order to improve its mobility skills for patients.

Nurses need help to transport patients from one place to another and also to assist the elderly and disabled people without risk of injury. It is advisable that elderly and disabled patients have an assistive aid which will allow them to move independently of the availability of medical staff to move them. Doctors want to move the patient without exerting physical effort and orderlies wish to facilitate the management of patients. Solutions to these needs lower the costs of the hospital. Figure 2 shows the main assistive proposals made to the HJM obtained according to the proposed methodology. Finally we get an analysis which let to choose the RB project to be developed (Table 4).

Once defined the developing device, performing a lifting specific requirements and based on these, a robot is designed considering mechanics, electronics, industrial design and software for its operation. The device obtained in this case study as a response to the needs of the HJM is a RB that is under construction. After the mechanical manufacturing, electronics and industrial design will proceed to the full assembly for testing the robotic attending the initial requirements.

CONCLUSION

This methodology is a way to perform the identification of the RB needs in a hospital, which leads to the identification of opportunity areas for the development of RB devices. It is important to have a methodology that assures that the solutions proposed respond to real needs.

In contrast, usually in Mexico today academic robotic project developments are done by attending only an idea of construction without considering if the robot is needed or not by society. Our methodology considers factors that minimize the risk of project development failure, as a consequence, it is very convenient to hospitals, companies and research institutes that develop RB. This methodology can be applied to rehabilitation engineering and the clinical fields providing concrete solutions to the most important needs detected in hospitals. The method allows the people in a hospital to show the most important areas that require RB technology. It also allows decreasing the operational costs of the hospitals. Once a technical proposal is qualified as viable according to our methodology, the robot or the assistive device can be manufactured.

This proposal may be used by the private and government sector of health like ISSSTE, IMSS, SS, PEMEX, SEDENA and Marina. The vision is that RB could help elderly and disabled people or patients to develop their activities or live in a better way with few efforts and less cost.

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