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Development Of A Method To Identify A Suitable Storage, Commissioning And Transport System By Focussing On Automation, Versatility And Costs

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Abstract

Storage planning is an important element of the factory planning and a significant competitive factor in times of an increasing global market [1]. The selection of a suitable storage, commissioning and transport system (sct system) is a major challenge for companies, because of the increasing number of new sct systems with different features. The level of automation and versatility of these systems are intransparent and the required level of both for a certain company is unknown [2,3]. To identify the level of versatility of sct systems a method based on versatility characteristics assigned to the versatility enablers was developed [4]. To determine the required versatility of sct systems for a particular company, a catalogue of change drivers was created. For the level of automation of sct systems, the requirements resulting from product characteristics and performance requirements of the warehouse were identified. The performance of the sct systems depends on the automation level, which can be set by influencing factors such as the degree of digitalization. The required level of automation must be determined by restrictions of the company and the identified possibilities of the systems [1]. At the same time, it is required to consider the costs of the systems as well as their possible combinations. Therefore, to save costs, the aim is also to consider systems which do not fit perfectly to the required versatility and automation level for a company but are still at an acceptable level.

Keywords

Storage, commissioning & transport systems; level of automation and versatility; logistics; selection support

1. Introduction

On the one hand, a huge number of different systems, an increasing number of new features in systems, and the intransparency of the required level of automation and versatility make the selection of a suitable sct system complex. On the other hand, the customer demands for a wide range of variants and a fast delivery is increasing. Hence, an efficient workflow of the logistics processes is essential to exist and survive on the global market [5]. The planning and investment in these systems are rare and of long duration and therefore qualified decisions must be made [6]. The versatility of their systems is a major challenge, especially for small and medium-sized companies (SME's), as this is important to be able to compete [7,8,9]. Existing versatility allows companies to adapt flexibly and quickly to changing conditions, like order variations and individualized products [10]. Furthermore, automation of the systems must be considered [11]. However, the question which individual automation level is useful to handle the storage tasks efficiently is hard to answer, especially for SMEs.

To support companies in their decision-making, a method for selecting and evaluating sct systems has been developed. The procedure and the developed partial methods are signed up in Figure 1.

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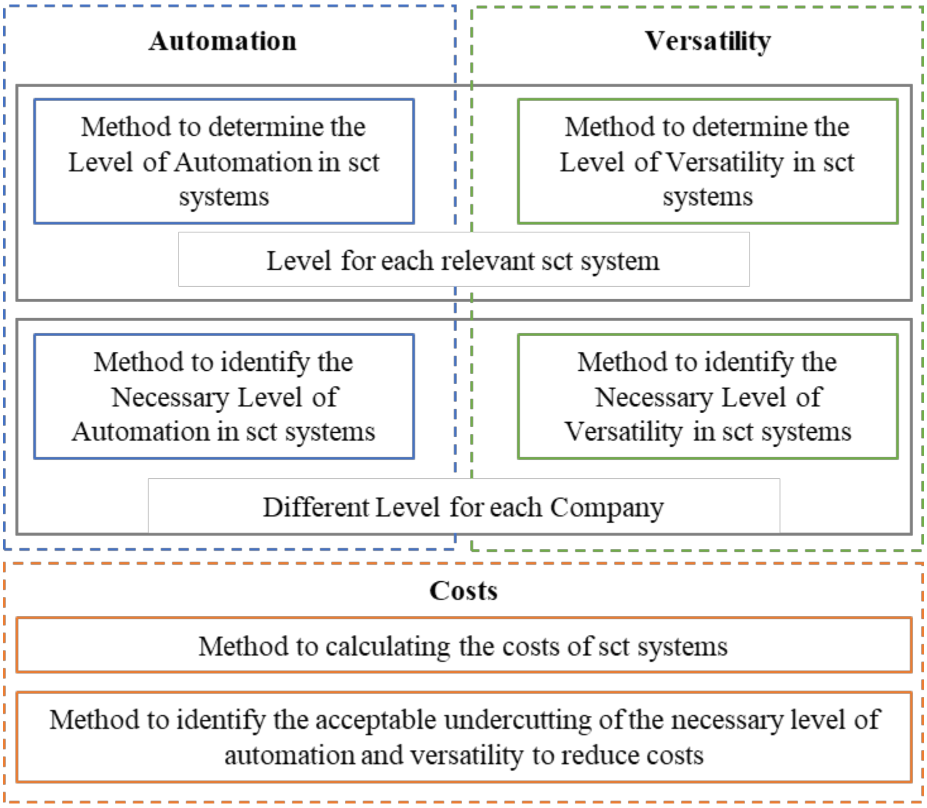

Figure 1: Method to identify a suitable sct system

The following section will first discuss the automation, starting with the method for determining the level of automation in sct systems. Then the method to identify the required level of automation required by the respective company is explained. After that the topic of versatility is elaborated. First the method to determine the level of versality in sct systems is presented, followed by the method to identify the required level for a company. To extend this, costs are considered in the next step. Within the analysis of costs, the first method is about calculating the relevant costs. The aim of the second method is to identify the maximum undercutting of the optimal requirements for automation and versatility, which are accepted to reduce the costs. The integration of costs is done via a filter structure. To support companies in their decision, the results are transferred to a tool, which will be shown next. In the end, the paper gives a conclusion.

2. State of the art

Automation is defined as "the result of automation, i.e. the use of automata" [12]. More precisely, it refers to the "(...) set-up and execution of work and production processes in such a way that humans do not need to be directly active for their sequence, but all processes take place automatically" [13]. The different levels of automation are defined as "the proportion of autonomous functions in the totality of the functions of a system or a technical plant" [12]. Use case specific degrees of automation of different systems can be found in the literature [e.g. 14,15,16,17]. The question of the right degree of automation and the selection of a suitable sct system is unanswered in literature.

A production system is versatile if there are no additional functional units needs if changes influence the storing situation [4]. For the determination of the level of versatility of sct systems and the individual required level of versatility the literature gives two suitable approaches [4,18], which were adapted to the consideration of the sct systems.

Investment appraisal comprises calculation methods used to determine the financial advantageousness of investment projects [19]. A bottom-up procedure, which is described in the literature, was used to estimate the costs of sct systems [20]. The approach to consider the three influencing factors: Automation, Versatility and Cost to select a suitable sct system does not exist in literature yet.

In addition to research in the areas of automation, versatility and cost, research work also exists in *sct systems*, where, for example, the current use of flexible and automated sct systems or their increase is addressed [21,22]. Approaches on performance evaluation (for a selection) also exists [23,24,25,26]. However, these works do not serve to determine the current as well as necessary versatility and automation under consideration of the costs for the selection of a suitable sct system.

3. Design and function of the partial methods in the automation

Automation is the sum of the functions that a system can perform independently, without human intervention. Automation can concern the topics regulation and control [12,13]. In order to identify a suitable sct system, it is required to develop a method to determine the level of automation of sct systems. After this a method to identify the required level of automation individually for each company is described.

3.1 Method to determine the level of automation in sct systems

To determine the level of automation, a difference is made between the categories *mechanization*, *computerization,* and *digitalization*. These categories are elaborated separately to ensure a detailed view [6]. The level of *mechanization* represents the replacement of human muscle power by automation solutions. It was divided into the areas of transport, storage and retrieval and identification of products [2]. Different levels are defined for the individual evaluation of the mechanization. Table 1 shows the classification using the area: transport. The five levels range from “manual work”, which is equivalent to no mechanization, to automatic functions, which correspond to the highest level of mechanization [6].

Table 1: Levels of mechanization “transport”

Category: Mechanization, Area: T*ransport*	Description
0	Manual work
1	Use of additives
2	Machine operation level 1
3	Machine operation level 2
4	Autonomic functions

Computerization indicates the level to which cognitive tasks can be performed with machine support. Computerization is divided into three areas: services before, during and after the transport. “Before transport” describes for example the task of putting the transport units together [29]. The level of computerization in this area range from no support for decision-making to autonomous decisions being made by the system. The area "during transport" is divided into five computerization levels and ranges from manual to autonomous navigation [31]. The area “after transport” deals with the identification of products. The levels range from manual input of information to automatic identification [6].

The level of *digitalization* is divided into four areas: networking at product level, system networking, data processing speed, and data analysis. The area "networking at product level" ranges from manual identification to automatic localization, for example via GPS signals [2,6,31]. In the area "system networking", the lowest level has no communication between the systems. At the highest level, the systems communicate automatically. For “data processing” the level of digitalization goes from no digital support to real-time processing. The fourth area of digitization is “data analysis”, which is divided into four levels based on the data mining context. The levels range from no data analysis to the ability to make own decisions, which is the maximum level of digitalization in this area [2,6,27]. With these levels of automation in the different categories (mechanization, computerization, and digitalization) and their areas the level of automation of each sct system can be determined. If one of these areas does not influence the system types, the area is not included in the calculation. It is also possible that an extra feature could level up a system, especially in the part of digitalization, for example a simple Forklift can be levelled up by an integrated scanner system or a GPS-signal, which has to be notice in the application.

3.2 Method to identify the required level of automation in sct systems

The required level of automation is identified in three steps. In the first step the functional requirements are checked. In the second step the minimum level of automation is determined and in the last step the required performance is defined. Within the framework of the *functional requirements*, the company needs information about his product portfolio: Information about weight and dimensions of the storage unit is required. The *minimum level of automation* is determined according to legal guidelines. Systems that could bring a risk to employees are to be excluded. The company fills in a survey that was developed for risk assessment. For example, information on employees, such as age and gender, is requested. Because this process step only deals with physical support, only the category mechanization levels are considered here. The risk can be assessed by negative points, which were valued for each information [6]. In the third process step the required *performance of the systems* is determined. For this purpose, three performance indicators are identified for each System type. The classification of the performance indicators is shown in table 2.

Table 2: Classification of the performance indicators

Systems	Power indicators
Storage systems	- Storage/removal per hour - Storage utilization factor - Room utilization factor [28,29,30]
Commissioning systems	- Picks per hour - Error rate - Availability [30]
Transport systems	- Transports per hour - Utilization rate - Suitability for the execution of rush orders [30]

Computerization and digitization are also considered in this step. The company selects which level as described in the previous section they want to reach. In this way, a matching with the sct systems can take place, because they have been evaluated in the same way. Systems which do not fit can be excluded [2].

3.3 Matching

These two methods around the topic of automation are merged in the order of the above-mentioned process stages via a filter structure. In the end, the company receives a pool of systems that fulfill the functional requirements, the minimum level of automation and the performance indicators. Under the assumption that a higher level of automation increases the costs, the optimal system in this pool is the one with the lowest level of automation. However, all possible systems are displayed for further evaluations [6].

4. Design and function of the partial methods in the versatility

Versatility describes the potential to carry out organizational, technical, and logistical changes with low investments, with consideration of the interactions of the system elements, and if necessary, in a short time [31]. The procedure for selecting sct systems with regards to versatility is like the procedure for automation. It is required to classify the examined systems and compare them with the required versatility of the company. In the first part the method for determining the versatility of sct systems is presented. In the second part the method to identify the required level of versatility is shown, followed by the resulting matching.

4.1 Method to determine the level of versatility in sct systems

To identify the versatility of sct systems, two valuation approaches are combined and oriented towards sct systems [4,17]. Both procedures result in a catalogue of characteristics defining the versatility enablers. In this case three tables have been developed, under constant consultation with experts, one for each system type. Table 3 shows the characteristics of the versatility enablers for storage systems.

Table 3: Characteristics of versatility enablers for storage systems

Versatility enablers	Characteristics
Universality	- Product and variant flexibility - Nominal capacity etc.
Mobility	- Degree of connection - Spatial mobility
Scalability	- Expandability
Modularity	- System architecture
Compatibility	- Operability - Documentation etc.
Object specific potential for change	- Commissioning

For each characteristic different execution have been identified and evaluated. For example, the characteristic “Product and variant flexibility” has the executions: Not fulfilled, sporadically fulfilled, partially fulfilled, largely fulfilled and fulfilled. In this case the rating is 0, 25, 50, 75 and 100 percent. Every characteristic has its own executions and suitable ratings. Overall, the combination of the different execution ratings for each characteristic resulting in a degree of fulfilment and the percentage of versatility for each enabler and hence also each sct system [6].

4.2 Method to identify the required level of versatility in sct systems

The required level of versatility in sct systems is determined by using a catalogue of change drivers based on the research project “WaProTek” [3]. In this catalogue all change drivers, which can influence the factory objects, are listed. Based on this procedure, the method to identify the required level of versatility for sct systems was developed. First, all relevant driver clusters were identified. In the context of sct systems, the following driver clusters were created: legislators and associations, suppliers, competitors, companies and network, globalization, digitization, employees, and technology. The different change drivers for each driver cluster must be identified. Definitions of the change drivers and related questions about them were formulated. By answering the questions with "does not occur", "occurs occasionally" or "occurs frequently", companies can evaluate the drivers. To assess the required versatility, the next step assigns the various drivers to the versatility enablers, which could counteract the change driver. The drivers can also influence more than one enabler. Table 4 shows one line as an extract of the change driver cataloque.

Table 4: Change Driver Catalogue Extract

Driver cluster	Change drivers	Definition	Question	Answers	Enablers
Suppliers	Changed order quantities	The order quantity describes…	Does your company experience changed order quantities by the supplier?	does not occur	Universality
				occurs occasionally	
				occurs frequently	

For the evaluation of the required versatility by the individual characteristics, the possible answers of the driver questions are weighted in the following dimensions: "does not occur" = 0%, "occurs occasionally" = 50% and "occurs frequently" = 100%. The different drivers and driver clusters are of different importance for determining the required versatility. Therefore, a pairwise comparison is carried out for identifying the weight. This results in the required percentage of versatility in sct systems for an individual company [6].

4.3 Matching

To match the required versatility to the versatility in sct systems, the results can be directly combined. In both methods, the result is a percentage of the versatility enablers, which allows a direct matching [6].

5. Design and function of the partial methods in costs

A survey of companies has shown that in addition to automation and versatility costs are a key factor in the selection of sct systems. This result can be transferred to the entire SME sector [32]. Therefore, costs have to be integrated in the process of selecting sct systems. It has to be analysed whether a cost reduction can be achieved by falling below the identified optimal level of automation and versatility. For this, the first part of this chapter focusses on a method to calculate the costs. In the second part the requirements which allows an undercutting are described.

5.1 Method to calculating the costs of sct systems

The cost estimation was made by a modification of the bottom-up procedure [19,33]. The costs for sct systems were initially determined individually. After that, the total costs were calculated by adding the partial results together. The data input were selected in consultation with the research project-accompanying committee. To make the results comparable all costs must be extrapolated to one year. The following cost drivers influencing the sct systems were determined: Acquisition costs, installation costs, other IT costs, average maintenance and energy costs, number of employees in normal business operations and the depreciation period and method. Acquisition costs, installation costs and other IT costs are non-recurring expenses that arise before the system is put into operation for the first time (installation costs). This includes the costs of the system itself and all other costs such as the cabling, which is required to put the system into operation. There are different procedures for the calculation of depreciation method, which depends on the individual business objective. Straight-line depreciation is chosen for the specific application. This is easy to implement and allows good comparability over the entire life cycle. It is assumed that the systems have no residual value after complete depreciation, are no longer usable, and no disposal costs are incurred. The energy costs and the number of employees required are based on an average utilization of 80%. These cost drivers must be extrapolated to one year to ensure comparability. The average maintenance costs are also calculated to one year. The following calculation is done for each system. Table 4 defines the parameters.

$$\emptyset K_S = \frac{K_A + K_{IN} + K_{IT}}{t_A} + \emptyset K_W + \emptyset K_E + N \times \emptyset K_N \times t_N$$

Table 5: Declaration of the formula

Symbol	Declaration
$\emptyset K_S$	Average costs of the system per year
K_A	Acquisition costs
K_{In}	Installation costs
K_{IT}	Other IT costs
t_A	Amortization period
$\emptyset K_W$	Average maintenance costs per year
$\emptyset K_E$	Average energy costs per year
N	Number of employees in normal business operations
$\emptyset K_N$	Average labour costs per hour
t_N	Working hours per year

For the purpose of this paper it is not required to go into more details of the cost drivers. A view on this level gives enough output about the resulting costs for the use of sct systems. The costs of each system are stored in an individual profile. All cost factors are listed, and the average yearly costs are calculated. This profile will be filled up more and more over the time.

5.2 Method to identify the acceptable undercut of the required level of automation and versatility to reduce costs

First, it must be determined in which areas of automation a lower level is permissible for reducing costs. It was found out that the functional requirements and the requirements for mechanization cannot be undercut. The functional requirements are fixed, because it is not possible to handle a storage unit with not functional fitting systems. The requirements for mechanisation are the second fixed category, because they deal with the health of the employees. A lower automation level is not acceptable in order to not endanger the employees in their daily working tasks. In the cases of computerization, digitization and performance indicators, an undercutting is permissible. Regarding versatility, an undercutting of all versatility enablers is generally allowed. However, the risk of not being able to react extensively enough to future changes in external circumstances must be considered by the companies. Company specific requests (according to the answers in the survey) are used to determine the permissible undercutting. The result is a corridor with systems that are accepted despite the deviation from the optimum. This corridor is based on the company's individual decisions. There are two possibilities for determining the permissible undercut. One option is to define a fixated level of permissible deviation. In the second option each company sets their own limits. In this case, the permissible deviations are made accessible by company-specific queries and thus by individual decisions of the companies. This approach requires an understanding of how the methods are working, the importance of the selection, as well as the possible consequences of the decisions. The advantage is that all company specialties of each company can be accounted for. The query resulted in a corridor on the axes automation and versatility, with systems that are accepted despite deviations from the optimum (Figure 2).

The coordinate system visualises the automation and the versatility executions on the axes. The circles represent the sct systems and the dotted borderlines together with the green area show the optimal level for a particular company. Without the consideration of the costs, the green marked area presents all suitable systems. With the drawn corridor (dotted green rectangle) further systems are considered for the pool of possible systems, with the precondition that these systems would reduce the arising costs compared to all optimal systems. All systems out of the green area and the costs saving corridor are not suitable.

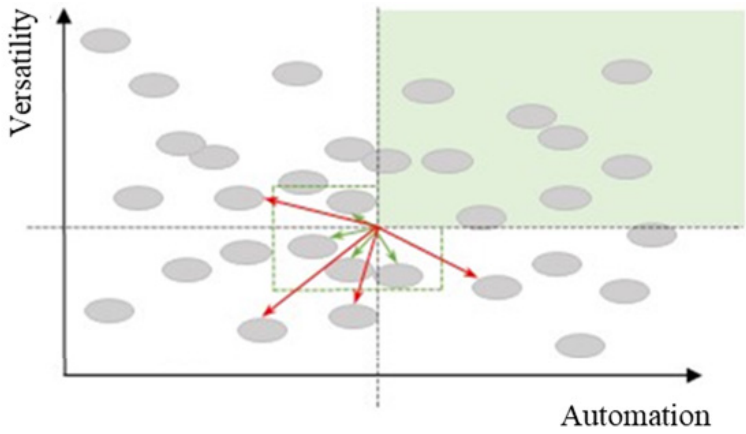

Figure 2: Permitted areas of automation and versatility and corridor for cost savings

6. Method to identify a suitable sct system by focussing on automation, versatility, and costs

For the combination of these partial methods to one overall method, a filter structure is used so that the relevant systems have to go through all the methods of evaluation (Figure 3).

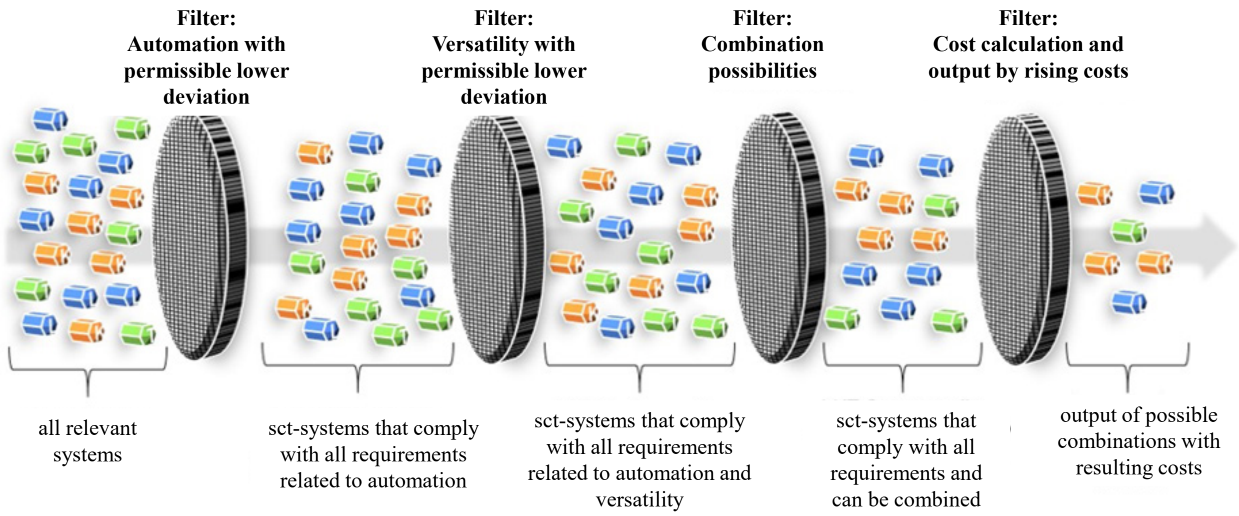

Figure 3: Filter structure

The *first filter* summarizes all the key points of automation. The filter excluded all systems, which are not functional suitable for the storage units. The minimum level of automation includes the mechanization levels and presents the first filter. Systems that do not meet the minimum level of mechanization to be achieved, are excluded. The level of computerization and digitalization are also surveyed when determining the required level of automation. Because some levels can also be achieved through a combination of systems and/or additional products, this has been added. The affected systems, which bring the possibility to reach a level but are not able to do it independently are marked for further evaluation by the company and cannot be excluded here. There is a note that an additional product is required for certain services [6]. Undercutting is possible within the permitted limits in the relevant areas. Information about the undercutting options must be given by the company.

Filter two compares the required characteristics of the versatility enablers with the characteristics of the specific company and the possible undercutting. For the identification of the required versatility, the versatility enablers and the change driver catalogue are used. After answering the questions of the change driver catalogue, all systems are excluded, which do not correspond to the required characteristics of the versatility enablers. Possible undercutting was given again by the company.

In the *third filter*, the systems that are standalone suitable by the selection are examined for combinability. For all possible combinations that are within the optimal range or within the permissible undercutting, the filter is open.

The *last filter* considers the resulting total costs per year. All systems which are in the range of optimal systems depending on automation and versatility automatically pass this filter. The systems, which are in the acceptable corridor to save costs are compared to the cheapest system in the pool of optimal systems. When the costs are lower the systems pass the filter, otherwise they are excluded in this step. The output of the last filter presents the possible sct systems for the specific company.

7. Transfer into an application

The filter structure explained above also corresponds to the query in the application. It starts with the questions about the functional requirements. Here questions about the product portfolio are included. This is followed by the determination of the minimum level and the query of the performance indicators, including questions about the computerization and digitalization requirements and the possible undercutting. After that, the consideration of the versatility is following. The companies must answer questions from the different driver clusters. In the background, the required characteristics of the versatility enablers are calculated in percent and compared with the existing characteristics of the sct systems. The resulting percentage will be shown, and the company can decide if an undercutting is allowed. Then the suitable systems are checked for possible combinations. To answer these questions, it is possible that some companies, especially SMEs will first have to provide the data. Descriptions of the needed data are stored in the tool for this purpose. With this application a high level of prior knowledge and experience is not needed anymore, so SMEs can make qualified investment decisions by themselves. This was programmed using VBA in excel. Via a user interface the company is guided through the questions and receives additional information to answer the questions. When presenting the results, all systems and their characteristics are visible. Thus, the company is given the suggested optimal systems, but can still view all excluded systems and understand why which systems were excluded by the software demonstrator. In addition, the company is provided with descriptions of all sct systems [6].

8. Conclusion

Sct systems and the resulting logistics processes influence the efficiency of companies. In order to support companies in the selection process of a suitable sct system, a method has been developed to select sct systems considering automation, versatility, and costs. In addition to the possibility to determine the required level of versatility and automation and to display the corresponding systems, corridors are determined that show which systems should be considered for cost saving reasons. Thus, possible potential for cost reduction arise, if the companies are ready to do dispense of automation and/or versatility level.

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Biography

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