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Procedia CIRP 15 (2014) 337 – 342
www.elsevier.com/locate/procedia

21st CIRP Conference on Life Cycle Engineering

Effects of climate change on factory life cycle

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Abstract

Climate change and global warming have negative consequences for humans and nature. While many research activities analyze the effects of industrial production on global warming and aim to develop actions using rare resources more efficiently and reducing CO_2-emission, the effects of climate change on industrial production is rarely discussed. Hence, manufacturing companies are considered in research as cause of climate change and not as affected by climate change. Thus, there is no systematic consideration of effects of climate change in factory planning. This leads to expensive adaptions within factory life cycle. For this reason the paper identifies ecological, economical and social changes caused by the climate change. These changes are analyzed on their effects on factories and prioritized according to their risk for the company. Subsequently, the identified changes are matched to different functions of factory planning. The matching allows developing planning-related and preventive strategy to cope with changes during factory life cycle.

Selection and peer-review under responsibility of the International Scientific Committee of the 21st CIRP Conference on Life Cycle Engineering in the person of the Conference Chair Prof. Terje K. Lien

Keywords: Factory Life Cycle; Climate Change; Global Warming; Factory Planning; Advanced Industrial Management

1. Introduction

According to the climate policy of the United Nations, global warming should be limited up to two degrees compared to the level before the industrialization. The consequences of this are intensive changes in conditions of living. Several research studies forecast that this target can be only achieved by drastic reduction of CO_2 emission within a small time frame [1]. Most research activities try to analyze the effects of industrial production on global warming and aim to develop actions using rare resources more efficiently and reducing CO_2 emission (e.g. Kyoto Protocol, EU Emissions Trading Scheme). However, the reversion of this argument how climate change will affect industrial production is rarely discussed.

For this reason, the paper introduces ecologic, economic as well as social changes caused by the climate change. This paper describes a solution how to deal with these impacts by using a 6-step-approach. The approach is a systematic way to derive specific risk out of the impacts of the climate change. The changes are analyzed concerning to their effects on factory elements and factory life cycle phases. These effects are evaluated by the probability of occurrence and the damage level. Subsequently, the identified probability and damage level are determining risk levels, which are prioritizing the risk of effects on different factory life cycle elements. According to the risk type, a strategy can be developed that considers targeted measures for specific risks.

2. Factory Planning

2.1. Factory Planning and Factory Life Cycle

Factory planning is defined as a systematic, object-oriented process to design a factory. It is structured into a sequence of seven phases with its own methods and tools (see figure 1) [2]. There are different factory planning processes, e.g. VDI planning process or the IFU reference model for the factory life cycle. The IFU approach has a wider scope than the VDI planning process, because it concludes the factory life cycle phases. The factory planning starts with the enterprise analysis and ends with the shutdown, which is the end of

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doi:10.1016/j.procir.2014.06.012

production. It is often necessary to adapt and to tune the factory to improve performance of the factory. These iterations are also included in the reference model [3].

In phase 1 **enterprise analysis**, the objectives in factory planning are deduced from the enterprise objectives and are specified according to the specific requirements of the factory planning project. The project team has to gather all required information during the as-is-analysis and adapt the information for the following phases. The goal is a definition of all tasks in the project of factory planning. At the end of the first phase, the project is evaluated and the management makes the decision whether the factory planning will continue. The **general planning** can be seen as the core task of the factory planning process, because the whole factory is designed (phase 2). It starts with the location finding. After the structure planning and dimensioning, an ideal layout is prepared. Based on this ideal layout different layout variants are generated which are considering restrictions. Also, the material flow and the material handling are planned. These variants are evaluated according to the defined objectives. The best variant is the input for the next phase, **detailed planning** (phase 3). Within the detailed planning, the selected variant is developed to a level of maturity for the implementation. The results are a detailed description and the visualization of all factory elements. The following phase is the **implementation** (phase 4) and the results of previous phases are put into action the first time. This phase also includes implementation controlling (monitoring, coordination and documentation of the realization process) and the production ramp up. The planning activities are performed in teamwork that is controlled by project management methods. The entire planning process is supported by project management [2,3]. **Operation** (phase 5) has the longest duration of all life cycle phases. The task of the factory planner does not end with the implementation because there are still smaller improvements steps or ramp ups of new products. The task is to assure the capability and efficiency of the factory. **Tuning** enables the provision of the facilities with the required resources at the designated place of installation. **Adjustment** is the displacement or expansion of the factory. The **shutdown** of the factory is the end of factory life. The factory becomes industrial wasteland or it may be re-utilized or revitalized for future users' needs [4]. Due to revitalization, the planning process starts again [3].

The IFU reference model is focusing on life cycle phases. Another focus on factory life cycle is present utilization value of the different levels of factories as shown in figure 2. According to the different lifetime of technological products, processes, building and land use, the life cycle and the present utilization value differs. The value of the land use is almost constant in the long-term. Only pollution like oil pollution of the ground has a negative influence on the value. The connections between the elements of the factory life cycle are based on following [5]:

- **Product:** According to customers demand, the product life cycle is getting shorter.
- **Process:** This element is influencing the production system. The process life cycle is planned for one or more product life cycles. It is adapted to the product life cycle.
- **Building:** The building equipment is based on product, process and production system life cycles. It needs to be adapted to changes in production system life cycles.
- **Land use:** The land use life cycle is oriented on the reuse of redeveloped areas with existing infrastructure (area recycling)

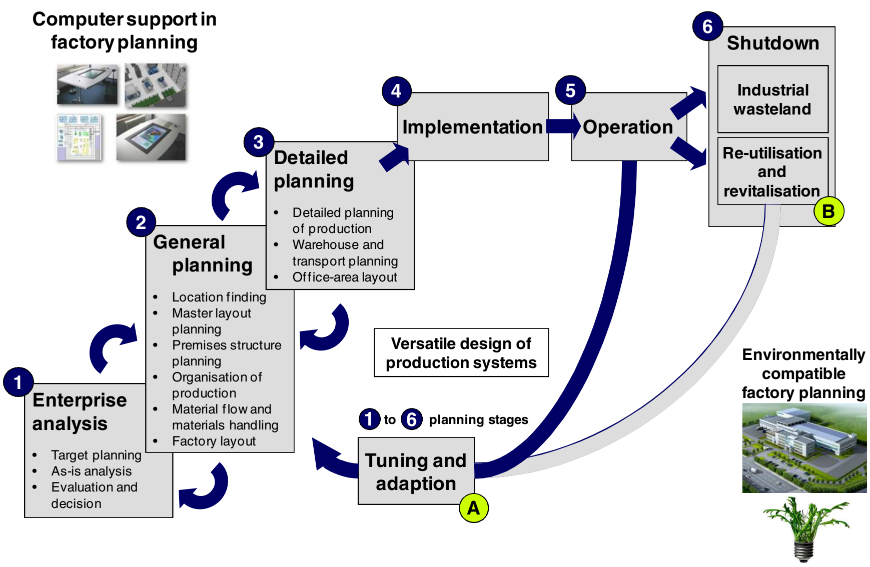

Fig. 1. Reference model for factory life cycle

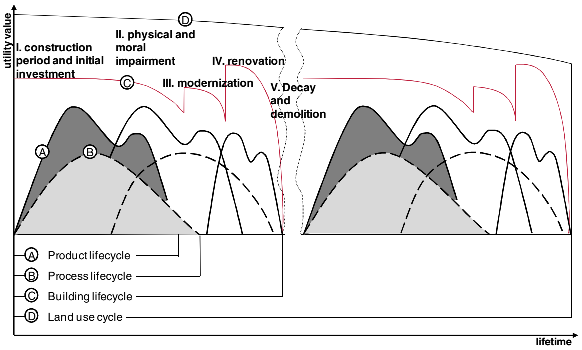

Fig. 2. Utility value of different life cycles. [5]

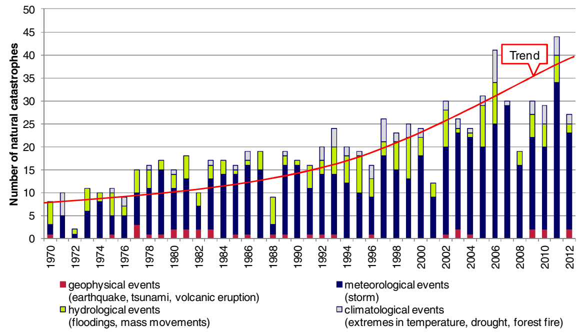

Fig. 3. Natural disasters in Germany 1970 to 2012 [10].

2.2. Research gap

The factory life cycle is determined by the product and process life cycle and requires changeability of the factory as well as a synchronization of the different life cycles. The solutions are changeability and the improvement of the flexibility of life cycles (to synchronize them) [5]. This is a field of past and present research in factory planning. But there is a lack of research about climate change and factory planning. Some of the conventional factory planning approaches in research are supposing the climate for a factory location as static, so that they consider climate for dimensioning the air conditioning [5-7]. Others try to reduce the negative impact of the factories on the climate change by reducing CO_2 emissions [8,9]. The duration of the factory life cycle shows a need for the consideration of long-term trends like climate change. Greenfield factory planning projects should take changing climate conditions into account. Nevertheless the majority of factories were build-up years or decades ago. Hence, the effects of climate change were not as intensive as they are today. For this reason, the next chapter describes climate change and its effects on factories.

3. Climate Change and its effects

This paper will not discuss if global warming is manmade or not, it discusses the effects of global warming on factories.

3.1. Theory of climate change

Since the industrialization began, humanity started to pollute a large amount of CO_2 into the atmosphere, which was stored in fossil energy sources, like coal. The consequence is an increase of CO_2-amount in the air from 280 ppm in the year 1850 to 367 ppm in 2000. This is a raise of 31 percent within 110 years. The result of CO_2 is that sunrays, which are reflected by earth's surface, are reflected again. The consequence is a higher temperature in the atmosphere. The so called natural greenhouse effect is strengthened due to the higher manmade amount of CO_2 (anthropogenic greenhouse effect). According to that, the average temperature is rising. The higher average temperature is just one effect of the changing climate. The climate change causes health, agriculture, forests, water resources, coastal areas or biodiversity [1]. Other serious effects like the sea level rise and the higher frequency of extreme weather. The increasing frequency of extreme weather events can be shown by the number of natural disasters in Germany (see figure 3). The total number of disasters is classified in hydrological disasters (e.g. floods, landslide), metrological disasters (e.g. storms) and climatologically disasters (e.g. heat/cold wave, drought, forest fire) and geophysical disasters. Compared to the 1970s, there is a significant increase in the first three types of disasters which are related to climate change [10]. Except the disasters, there are other effects like rising or falling precipitation amounts, changing average temperature, changes in agriculture, etc [11]. Not all changes have an impact on the factory. The relevant effects are described below.

3.2. Effects of climate change on factories

The economy of industrial nations is still based on manufacturing companies. The building envelope of the factory is a place for value adding activities and there are countless factories all over the world. The changing climate conditions are affecting these factories in different ways. Especially extreme weather events have an effect on factories. For example, tornados can blow away roofs or the snow load can lead to a collapse of the factory with the likely result of seriously injured or dead victims. These events need to be taken into account. The effects of climate change were identified by a literature analysis (e.g. [1,12-15]) and selected by an expert evaluation according to their relevance for the factory. The effects can be clustered into three groups: ecological, economical and social effects. Ecological effects are describing the changes in the environment and the climate conditions. Economical effects are consequences on business and supply chains derived from the ecological effects. Thirdly, social effects are chances like new governmental restrictions, immigration or customer behavior. The following effects will be considered in further analysis:

Ecological effects

- Amount of precipitation: heavy rains, annual amount, droughts
- Temperature curve: cold/ heat waves
- Storm
- Floods due to heavy rains and sea level rise

Economical effects

- Higher susceptibility of a collapse of global supply chains due to higher frequency of extreme weather events
- Higher costs for prevention activities
- Higher prices for insurance

Social effects

- Refugees due to deteriorate climate conditions (e.g. sea life rise is flooding coastal areas in developing countries)
- Arising awareness of customers for climate change leads to the need for climate friendly production
- CO_2-limitation
- Prohibition of materials with a negative effect on climate (e.g. CFC ban)

Depending on local conditions and the characteristic of the factory, the intensity of each effect is varying and additional effects may need to be considered. For example, if water resources get scarce the competition between industry, private households and agriculture for water is getting harder. This is influencing water-intensive industries, like chemical industry or power plants. This may result in blackouts in summer which is affecting other branches.

4. Approach

The effects of climate change need to be taken into account within all phases of the factory planning process. Also the approach needs to be adaptable to be applicable in practice. Hence, the approach is a wide general approach that can be adapted to a suitable level of detail. It consists of 6 steps which provides a systematic development of strategies and supports the conservation of the factory's value. The first step determines the field of all possible applications by defining the level of detail and describing all factory life cycle elements. Afterwards, the field is limited to the relevant elements in the second step. During the third step, probabilities of occurrence of the effects of climate change are assessed for each factory element and life cycle phase. Then, the level of damage is determined for each combination in the fourth step. Step 5 contains the derivation of different risk levels which are visualized and classified in a risk portfolio. Finally, strategies are developed according to the risk level. Each step is described in detail in the following.

4.1. Step 1: Determination of the field of application

The first step is the determination of all possible factory life cycle elements that can be considered in the following analysis. A factory life cycle element can be characterized by the dimensions 'factory element' and 'life cycle phase'. Especially, the factory elements have a broad range of detailing. As described in paragraph 2.1, there are the four main factory elements product, process, building and land. If required, these elements can be detailed to smaller pieces. The second dimension is the 'life cycle phase'. This dimension can be divided according to the six life cycle phases of IFU reference model. The result of the first step is the definition of a matrix of the factory life cycle elements (see figure 4a). The

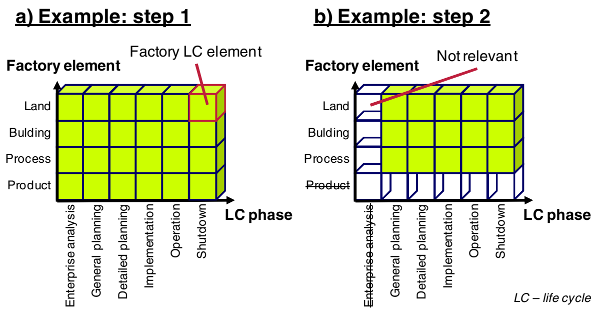

Fig. 4. a) Step 1: Matrix with factory life cycle elements.
b) Step 2: Selection of relevant elements.

n columns correspond with all possible factory life cycle phases (or sub-phases). There are *m* rows for each factory element.

4.2. Step 2: Selection of relevant factory life cycle elements

The further approach would get too complex, if all elements of the matrix would be considered in further analysis. Therefore, the relevant parts are selected by a comprehensive analysis or by a company-specific decision of the management. The comprehensive analysis consists of an impact matrix and a consistency matrix. These techniques support the systematic derivation of interrelations between different elements that are relevant for the selection [16]. Hence, specific factory life cycle elements, whole phases or factory elements that are not relevant can be excluded.

For example the factory element 'product' may be not relevant for climate change because its life cycle time is rather short. Also, the life cycle phase 'enterprise analysis' is supposed to be not relevant for the company analysis of the climate change. Hence, parameters of the first column and the lowest row can be deleted from the matrix (see figure 4b).

4.3. Step 3: Occurrence of effects of climate change

The effects of climate change are analyzed in step 3. A number of main effects are listed in paragraph 3.2. If additional effects influence the factory life cycle elements, they can be added. Each effect is considered in the analysis by a third dimension. Consequently, the matrix is expanded to a cube. Each field of the cube represents the impact of an effect of climate change of a factory life cycle element. The impact can be described with the probability of occurrence of an effect within the factory life cycle for a specific factory location. Figure 5 shows a cube whose fields contain the probability of occurrence which is stated between 0 and 1. From this it follows that a probability of 1 indicates that the effect takes place every year at least once and a probability of 0.3 that it occurs in three of ten years. The probabilities of occurrence are divided into the following six categories [17]:

- Inconceivable (probability of <0.02)
- Not likely (probability of 0.02 to <0.1)
- Conceivable (probability of 0.1 to <0.2)

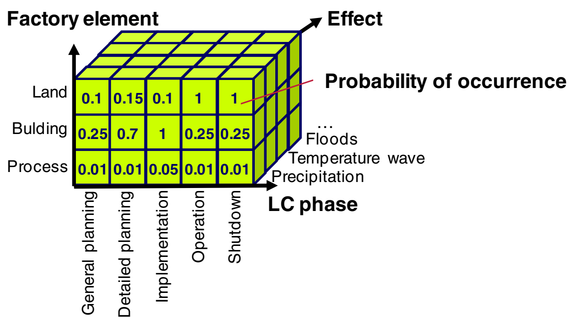

Fig. 5. Step 3: Three dimensions of probability cube (dummy data).

- Occasionally (probability of 0.2 to <0.3)
- Likely (probability of 0.3 to <0.8)
- Often (probability of 0.8 to 1)

According to the example, there is a probability of 1 that the amount of precipitation has a negative impact on building during implementation phase. The probability within the life cycle phase operation is between 0.2 and 0.3, because it is less likely that negative impacts occur. Finally, all fields in the cube have to be evaluated.

4.4. Step 4: Estimation of the damage level

The forth step contains the estimation of the level of damage if the effect of climate change occurs. Each factory life cycle element gets assigned a level of damage for every effect. The following four levels are distinguished [18]:

- **Negligible:** if the effect occurs, there will be no negative impact on the factory life cycle element.
- **Moderate:** if the effect occurs, it has an impact on the factory life cycle element. Nevertheless, there is just a minor damage.
- **Critical:** if the effect occurs, it will hurt the company very much so that it has a huge damage. But the effect will not be existence-threatening for the factory.
- **Catastrophic:** A catastrophic damage has a big negative impact on the factory element; it is seriously existence-threatening for the factory.

For example, the damage of a higher amount of precipitation has a very high damage on the factory operation, because the factory's roof is leaky. Also the factory's location is in a flooding area of a river with the result that flooding of the building is getting more likely. Hence, the level of damage is critical to catastrophic.

4.5. Step 5: Derivation of risk level

The probability of occurrence and the level of damage can be combined to a risk portfolio that shows a specific risk for certain combinations. A reasonable tool for visualization this context is the risk portfolio shown in figure 6. One dimension of the matrix is the level of damage with the four categories of step 4. The other dimension is the probability of occurrence

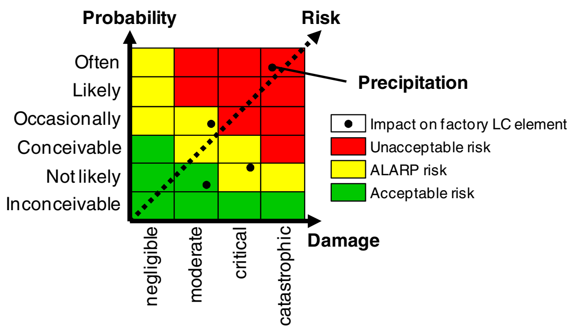

Fig. 6. Step 5: Risk portfolio with risk types.

from step 3 which are clustered into six categories. Hence, the matrix has 24 fields which have a different importance for the factory. The field in the bottom left is representing low risk. On the very top right, there are the combinations with high risk. The risk portfolio with the example of precipitation is shown in figure 6.

4.6. Step 6: Strategy development

If all potential risks are indentified and classified, the factory management should develop strategies to handle the risk. The risk types are [19]:

1. Unacceptable risk
2. "as low as reasonably practicable" risk
3. Acceptable risk

Generally, all risks should be avoided. However, this is often impossible due to financial restrictions and conflicting goals. One the one hand, factories should not be located close to rivers in order to avoid floods. On the other hand, a river might be necessary for transportation or to avoid high costs for cooling water. In green field projects, unacceptable risks need to be avoided during planning. Practicable risks should be managed by appropriate risk strategies. Acceptable risks do not require special strategies but should be covered by insurance policies. In brown field planning, strategy development is more challenging. If unacceptable but avoidable risks exist, green flied strategies are applicable. Nevertheless, in brown field planning identified risks are often hard to avoid. This results from the limited degrees of freedom in such cases. Factories have to cope with unacceptable risks by adapting their factory elements.

5. Industrial application

In the years 2002 and 2013 there were 2 "flood of the century" in middle Europe with huge destructions in the German federal state of Saxony. Many companies were affected within a short period of time. If the approach were taken into account, companies would have strategies to handle the second flood or they would have relocated their factories to safer places. Nevertheless the approach is not a methodology to predict occurrence of effects of climate change. It is developed to identify and categorize risk in structured way. The goal is the definition of robust strategies to manage negative effects of the climate change.

A conceivable case study is a medium-sized company of the metal processing industry is located in flooding area of a river. The approach can be utilized to identify and evaluated the risk for the factory. For example the flooding (estimated probability of 0.1) would destroy power supply (factory life cycle element operation/building) that has high cost for rebuilding (unacceptable risk). A measure of the strategy is usage of waterproofed equipment and the emergency shutdown. Another possible strategy is the cooperation with local government and other companies to build a dam.

6. Conclusion

The approach shows that the consideration of the effects of the climate chance is very complex. The approach is a method that takes all relevant factory elements and life cycle phases into account in a very systematic way. Within the six steps of the approach, the analysis is getting more and more detailed and focused on relevant aspects. It starts with a comprehensive view on the total factory life cycle and its elements. Afterwards, the probability of occurrence and the level of damage for all elements and all effects allow a classification of risks. All elements are evaluated and an assignment to three risk classes gives a prioritization. For the high risk strategies need to be developed by using factory planning. Finally, the value of the factory life cycle can be preserved, because planning activities can be evaluated. Hence, the approach still requires managers and factory planning engineers that have the awareness and knowledge about the effects of climate change as well as competences to develop measures according to the strategies. Therefore, the qualification and education of engineers needs to be adapted to the described situation.

Actual, the implementation of the approach is prepared for application in companies.

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