INDUSTRY 4.0: OPPORTUNITIES FOR THE DIGITAL TRANSFORMATION OF THE R&D PROCESS FOR PAINTS AND COATINGS

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Abstract

In observing the transformation of firms from traditionally organised businesses into factories that could carry the Industry 4.0 label, it can be seen that not all industries develop equally quickly or successfully. Because competition is reflected primarily in relationships between firms within the same industry, when a particular industry lags other industries there is usually no problem until individual firms in the industry begin to change. These outriders quickly establish new standards that the laggards in the industry find difficult to meet. The paper examines the case of the revamping of development processes in the paints and coatings industry, which has the potential to become an outrider in the industry.

It was found that using an innovative digital platform *[AllChemist, 2019]* can largely eliminate process functions that do not add value, can significantly reduce the number of repetitions of certain process steps, and can shorten the development time. Implementation of the platform that provides for the revamping of the development process also brings other benefits. These will be further examined in the research, which is still ongoing.

Keywords

Digital transformation, Process transformation, Industry 4.0, Development process, Paints and coatings

1. INTRODUCTION

The research on which this paper is based was undertaken in 2018, and is still ongoing. During the research, snapshots of the development process for paints and coatings were taken at several firms of various sizes and organisational structures. The process snapshots were drawn up on the basis of structured interviews with professionals with detailed knowledge of the processes who conduct key activities in them *[Kern, 2008]*.

It was found that development specialists (in the development of paints and coatings they are known as formulators) have limited knowledge of potential ingredients of future products at their disposal. Information is generally obtained through enquiries made with producers, or from their own local or partial archives. Documentation (primarily technical data sheets and safety data sheets) *[ECHA, 2019]* is generally in paper form, or at best in unstructured electronic form (pdf). Formulators spend a relatively large amount of time searching for and determining the properties of suitable ingredients (binders, fillers, diluents, pigments and additives) from among those that they hold information about. Process analysis revealed that unstructured and deficient input information and the consequent need to repeat certain process functions result in poor process flow. The first step is laboratory testing, which is slow and expensive, and only after they have been deemed acceptable in laboratory testing are development products subject to analytical review and other validation. The majority of formulations tested are often found to be too expensive or environmentally questionable in the later phases of development.

Because market requirements are continually increasing, and environmental standards are getting more and more stringent, while product diversification is high, firms that develop and manufacture paints and coatings face a serious challenge. It was found that a potential solution could lie in a more efficient development process. The main factor in the revamp (i.e. the technological enabler) is implementing an innovative information platform being developed by one of the Slovenian firms *[AllChemist, 2019]*. The platform is based on a central repository of ingredients for the development and formulation of paints and coatings that are available on the market. An intuitive search engine makes information about ingredients available to development engineers (formulators), who can use a configurator to put together a functionally appropriate formulation or multiple formulations in a few steps. They can also conduct a real-time review from the perspective of cost-effectiveness and environmental acceptability. Only once an individual formulation satisfies the functional requirements and meets the other boundary conditions is it subjected to laboratory testing. This significantly simplifies and shortens the development process, but this approach also has other advantages.

2. SNAPSHOT

Models of multiple versions of development processes for paints and coatings were produced with the Aris tool *[Aris, 1998, Aris, 2008]*. Three modelling notations were used: the value added diagram (VAD), the function tree (FT) and the event-driven process chain (EPC). The models were recorded in a joint repository, which provides for analysis on the basis of structured and operational indicators and simulation.

Models were produced for the versions of processes in which information and communication technology is used, and versions where the process is undertaken without IT support.

These processes were recorded in a value added diagram at three levels of decomposition (see Figure 1).

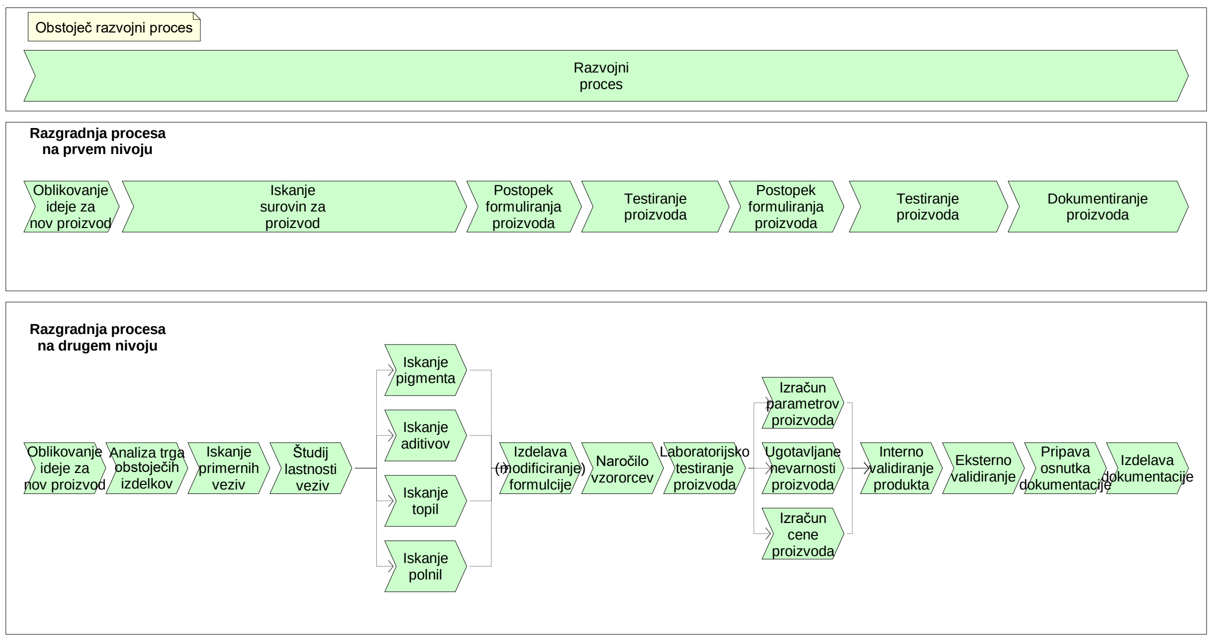


Figure 1: Example value added diagram of an existing development process for paints and coatings

obstoječ razvojni proces	existing development process
razvojni proces	development process
razgradnja procesa na prvem nivoju	first-level decomposition of process
oblikovanje ideje za nov proizvod	elaboration of idea for new product
iskanje surovin za proizvod	search for substances for product
oostopek formuliranja proizvoda	product formulation procedure

testiranje proizvoda	product testing
dokumentiranje proizvoda	product documentation
razgradnja procesa na drugem nivoju	second-level decomposition of process
oblikovanje ideje za nov proizvod	elaboration of idea for new product
analiza trga obstoječih izdelkov	analysis of market for existing products
iskanje primernih veziv	search for suitable binders
študij lastnosti veziv	study of properties of binders
izdelava (modificiranje) formulcije	creation (modification) of formulation
naročilo vzorcev	ordering of samples
laboratorijsko testiranje proizvoda	laboratory testing of product
izračun paramatrov proizvoda	calculation of product parameters
ugotavljanje nevarnosti proizvda	determination of product hazards
interno validiranje produkta	internal validation of product
eksterno validiranje	external validation
izračun cene proizvoda	calculation of product price
interno validiranje proizvoda	internal validation of product
eksterno validiranje	external validation
priprava osnutka dokumentacije	drafting of documentation
izdelava dokumentacije	production of documentation
iskanje pigmenta	search for pigment
iskanje aditivov	search for additives
iskanje topil	search for diluents
iskanje polnil	search for fillers

The third-level decomposition makes use of an EPC model in which all process steps, process owners, information holders, operators and statuses are described in detail (see Figure 2).

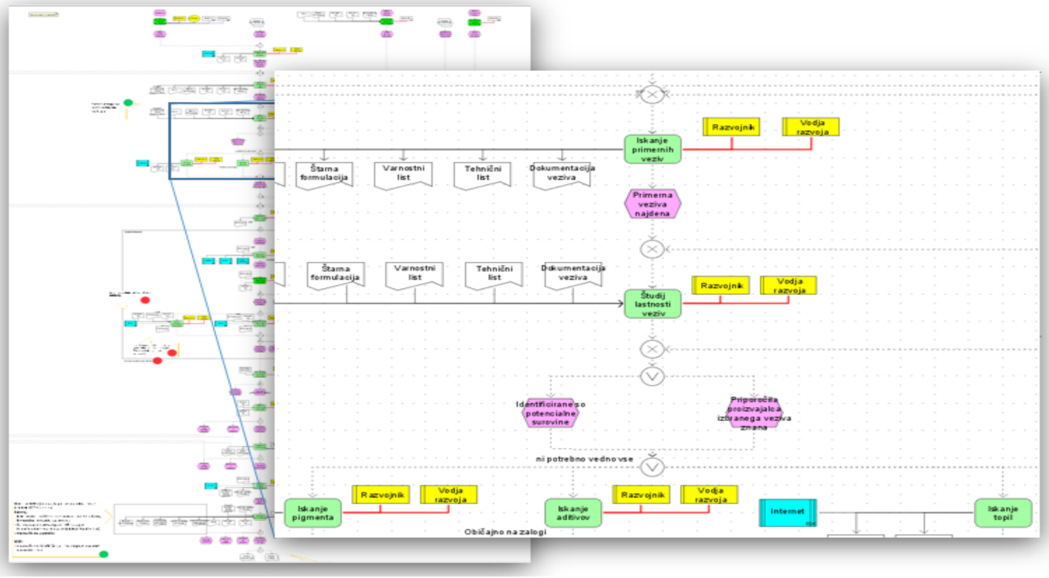


Figure 2: EPC model of existing development process for paints and coatings

Data about throughput times and structure was obtained for individual process functions.

The process function times were itemised to determine the proportion of times that do not add value to the process (see Figure 3). The following times were used:

- Waiting time: the time when the previous process has been completed, but the process function in question is not yet being carried out, because the process owner or another necessary resource is not yet available. Waiting time also includes the time when the process function in question has been completed, but work has not yet been handed over to the next process function. The two waiting times were functionally combined for individual processes in the research.

- Pre-processing and post-processing time: the times when the process owner (or another resource) is using its time, but work is not yet being carried out in the process function in question, or has been completed. Pre-processing and post-processing time were functionally combined for individual processes in the research.
- Processing time is the time of actual work in the process function, i.e. the time when the value is being added in the process.

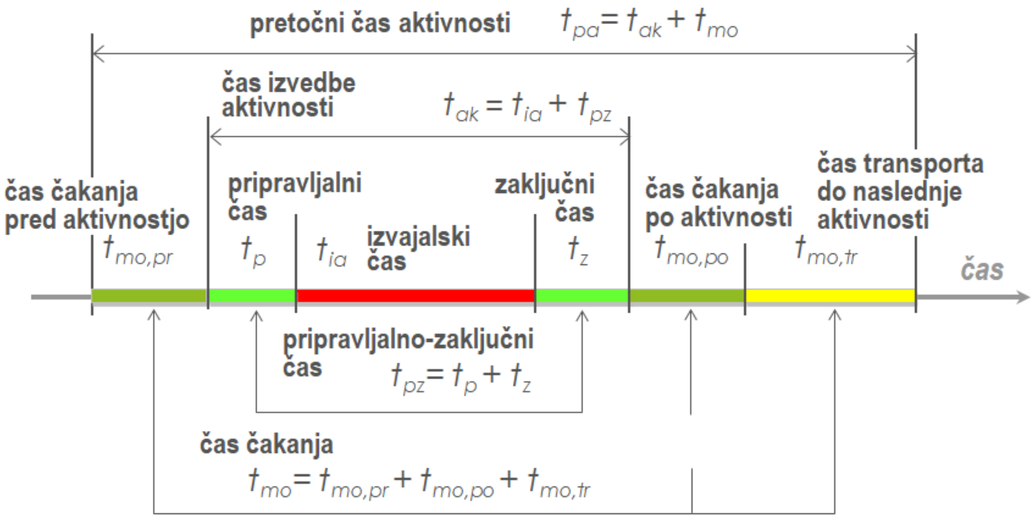


Figure 3: Time structure of a process function [Ljubič, 2006]

pretočni čas aktivnosti	throughput time
čas izvedbe aktivnosti	cycle time
čas čakanja pred aktivnostjo	pre-cycle waiting time
pripravljalni čas	pre-processing time
zaključni čas	post-processing time
čas transporta do naslednje aktivnosti	transit time to next activity
čas čakanja po aktivnosti	post-cycle waiting time
izvajalski čas	processing time
čas	time
pripravljalno-zaključni čas	pre- and post-processing time
čas	time
čas čakanja	total waiting time

Because it is a development process, it should be noted that the times of process functions are not the same in each iteration, on account of internal and external factors and the relatively low frequencies of repetition. A PERT method was therefore used to calculate expected times from optimistic, pessimistic and most likely times (waiting, pre-processing and processing times) for an individual process function *[Cottrell, 1999]*.

$t_e = (t_o + 4t_m + t_p) / 6$

- t_e: expected time
- t_o: optimistic time
- t_m: most likely time
- t_p: pessimistic time

Data about feedback loops in processes and the expected number of repetitions of a particular feedback loop was obtained for all processes modelled, from which it is possible to calculate the probability of advancement or repetition of the process step (see Figure 4).

##	Aktivnost v procesu	Ocene časov	Optimistično	Verjetno	Pesimistično	Pričakovano	Skupni čas	Verjetnost*
10	Oblikovanje ideje za nov proizvod	Čas čakanja	15,00	18,00	52,00	23,17	95,17	0,06
		Pripravljalno zaključni čas	3,00	8,00	45,00	13,33		
		Čas izvajanja	44,00	55,00	88,00	58,67		
20	Analiza trga obstoječih izdelkov	Čas čakanja	15,00	18,00	52,00	23,17	95,17	1,00
		Pripravljalno zaključni čas	3,00	8,00	45,00	13,33		
		Čas izvajanja	44,00	55,00	88,00	58,67		
30	Iskanje primernih veziv	Čas čakanja	0,20	0,40	1,00	0,47	4,72	0,92
		Pripravljalno zaključni čas	0,10	0,20	0,60	0,25		
		Čas izvajanja	2,00	4,00	6,00	4,00		
40	Študij lastnosti veziv	Čas čakanja	0,20	0,40	1,00	0,47	4,72	1,00
		Pripravljalno zaključni čas	0,10	0,20	0,60	0,25		
		Čas izvajanja	2,00	4,00	6,00	4,00		
50	Iskanje pigmenta	Čas čakanja	0,20	0,40	1,00	0,47	4,72	0,19
		Pripravljalno zaključni čas	0,10	0,20	0,60	0,25		
		Čas izvajanja	2,00	4,00	6,00	4,00		
60	Iskanje aditivov	Čas čakanja	0,20	0,40	1,00	0,47	5,72	
		Pripravljalno zaključni čas	0,10	0,20	0,60	0,25		
		Čas izvajanja	3,00	5,00	7,00	5,00		
70	Iskanje topil	Čas čakanja	0,20	0,40	1,00	0,47	1,80	
		Pripravljalno zaključni čas	0,10	0,20	0,60	0,25		
		Čas izvajanja	0,50	1,00	2,00	1,08		
80	Iskanje polnil	Čas čakanja	0,20	0,40	1,00	0,47	1,80	
		Pripravljalno zaključni čas	0,10	0,20	0,60	0,25		
		Čas izvajanja	0,50	1,00	2,00	1,08		
90	Izdelava (modificirane) formulacije	Čas čakanja	0,00	0,00	0,00	0,00	2,17	1,00
		Pripravljalno zaključni čas	0,00	0,00	0,00	0,00		

čas čakanja	total waiting time
pripravljalno zaključni čas	pre- and post-processing time
čas izvajanja	processing time
aktivnosti v procesu	activities in process
ocene časov	estimated times
verjetnost*	probability*
oblikovanje ideje za nov proizvod	elaboration of idea for new product
analiza trga obstoječih izdelkov	analysis of market for existing products
iskanje primernih veziv	search for suitable binders
študij lastnosti veziv	study of properties of binders
iskanje pigmenta	search for pigment
iskanje aditivov	search for additives
iskanje topil	search for diluents
iskanje topil	search for diluents
optimistično	optimistic
verjetno	most likely
pesimistično	pessimistic
pričakovano skupni čas	expected total time

Figure 4: Example of estimates of times of process functions and probability of advancement of the process

3. ANALYSIS OF THE DEVELOPMENT PROCESS

The process models and the data on the time parameters of process functions formed the basis for conducting analysis, and drawing up static and dynamic time simulations. The Aris tool was used for this purpose. The analysis revealed that the largest time loss in the development process is because of the (excessive) multiple repetition of laboratory testing. Repeated laboratory testing of different formulations occurs because formulators are trying to satisfy increasingly stringent requirements, where from the large number of ingredients available they have to choose the right ingredients in the right ratios. This increases the complexity of the development process significantly. The number of laboratory tests is further pushed upwards because it is only at the end of testing that the environmental acceptability of the product can be determined, and also its price. If not all properties fall within the boundaries of expectations, the development process returns to the beginning again.

In the review of the approaches already in use in industry to address this problem, the idea of reducing the time needed for each individual laboratory testing appears most often in the literature. There are several innovative approaches that advanced firms are already using or are only now at the planning stage, and they relate to new technologies and laboratory equipment. They both allow individual repetitions of laboratory testing to be reduced, thereby shortening the development process. However, these approaches fail to resolve the problem completely. Because the complexity of the requirements and restrictions is continually increasing, the results of introducing technological changes are not sufficient.

An alternative approach was examined in the research. Digitalisation concepts that are already in use in other industries and are providing excellent results were used *[DKE, 2018; Gartner, 2019]*. Here the guide was that technology alone cannot provide a complete solution. Technology can only facilitate a solution (in this case of process revamp). Two areas were studied in detail before the revamp of the process: new technologies, and the revamp of business processes.

It was found that radical improvements can be achieved primarily by reducing the number of repetitions of individual process functions, and not by increasing their efficiency unless they add value. Because laboratory testing is often repeated in the process in question, and it lies on a critical pathway, the focus was on the aforementioned process function. It was found that the number of repetitions could be reduced if the set of formulations that require testing was reduced before laboratory testing. This could be done by the appropriate selection of formulations that are suitable not merely in functional terms, but also in environmental and price terms. In particular, each formulation could be evaluated (mathematically) in environmental and price terms in advance without testing, because the assessments (calculations) depend solely on the ingredients of the formulation. Therefore if data on the ingredients were to be obtained in advance, the environmental and price acceptability could be calculated for an optional number of potential formulations, and the formulations that satisfy the conditions could be identified. Formulations that are unsuitable in environmental and price terms would thus not undergo laboratory testing. Only suitable formulations would be tested, resulting in a radical reduction in the number of repetitions of laboratory testing, and consequently in the process throughput time.

However, formulators would require data on potential ingredients that is up-to-date, and constantly available in an appropriate form. It was examined whether such databases exist. It was found that the majority of data on ingredients is publicly available, because it is found in safety data sheets, which are mandatory for chemical substances and products *[ECHA, 2019]*. The data is generally in unstructured form. It is found either in paper form, or in unstructured electronic documents (pdf). In addition, to obtain the data it is necessary to enquire with producers, which is a slow process. Documents of this type are therefore useless for revamping the development process for paints and coatings. It is easier and quicker for formulators to first conduct laboratory tests than to search for the data on a large number of potential ingredients, which are highly likely to be unsuitable.

Revamping the process therefore urgently requires an approach or technology that would allow for fast, simple access to data on potential ingredients. Existing technologies supporting development and production in the paints and coatings industry were studied. The AllChemist technological solution was identified.*[AllChemist, 2019]*. In essence, the solution provides information support to the completion phase in the development process, and provides for the production of safety data sheets and technical data sheets. It is a digital platform whose special feature is that it does not only provide for the creation of pdf documents on the basis of data from a local database, as is customary for such solutions. By contrast it is designed for the use of data from the global database in the cloud, and can be completed by producers of ingredients, and can be used by firms that develop and produce paints and coatings (Figure 5). The technical data sheet and the safety data sheet are merely extracts of structured data on ingredients, which can be printed as necessary. The data on ingredients that formulators transcribe from documents can be used directly to draw up the formulation of the product under development.

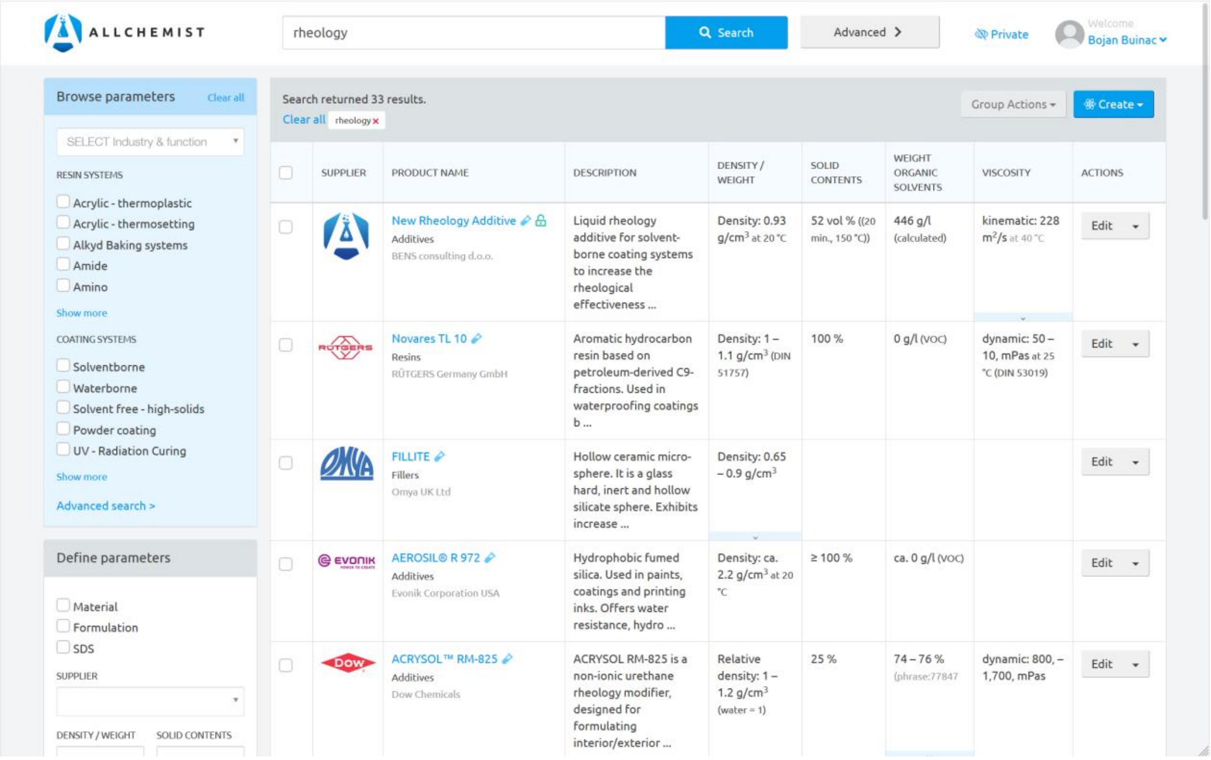


Figure 5: Screenshot of platform [AllChemist, 2019]

4. PROPOSAL FOR DIGITAL TRANSFORMATION OF THE DEVELOPMENT PROCESS

It was found that the platform could in fact be used in the initial phases of the development of the paint or coating, when the formulator is merely designing the formulation. Instead of conducting expensive and slow laboratory testing for a large number of possible formulations, and then further testing the technologically acceptable formulations in terms of environment and price, the process is reversed. Using a special configurator developed by the designers of the platform, the formulators design an optional formulation, and review the product's environmental acceptability in addition to its technological properties. If data on the price of ingredients is available, the internal price of the product can also be calculated. Simulations of possible formulations in AllChemist are first conducted. Those that are environmentally acceptable and whose price is within the tolerance limits are then tested. This means that a large number of fast, cheap computer simulations are first conducted, and only afterwards are a small number of slow, expensive laboratory tests conducted. The process can therefore be radically modified and shortened (see Figure 6).

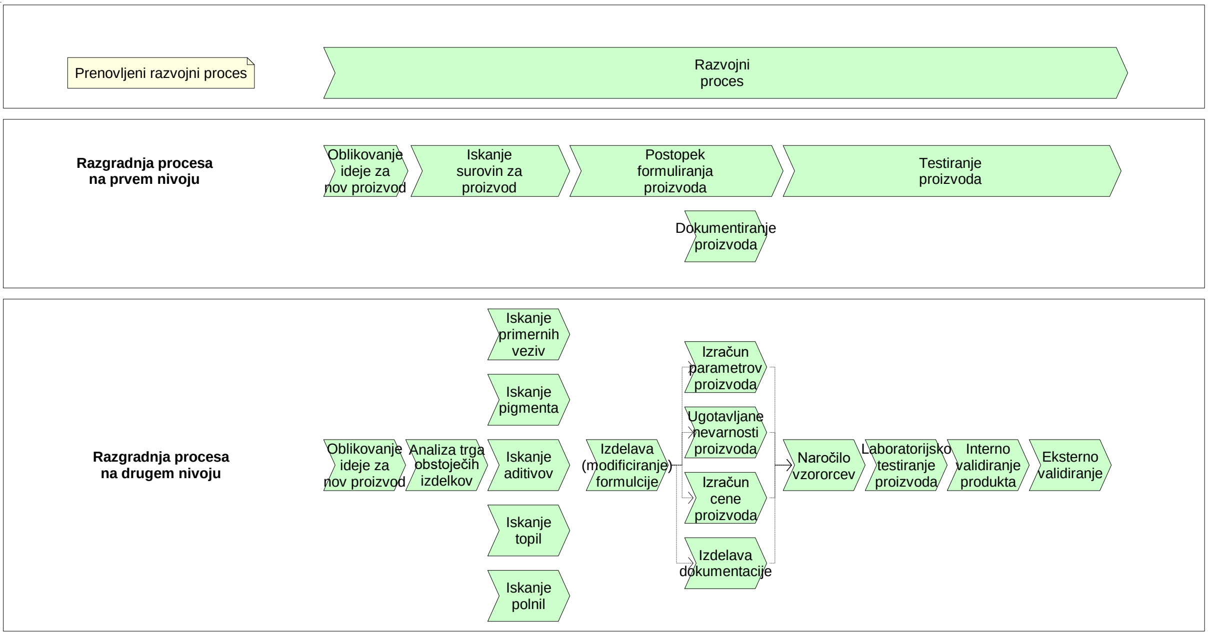
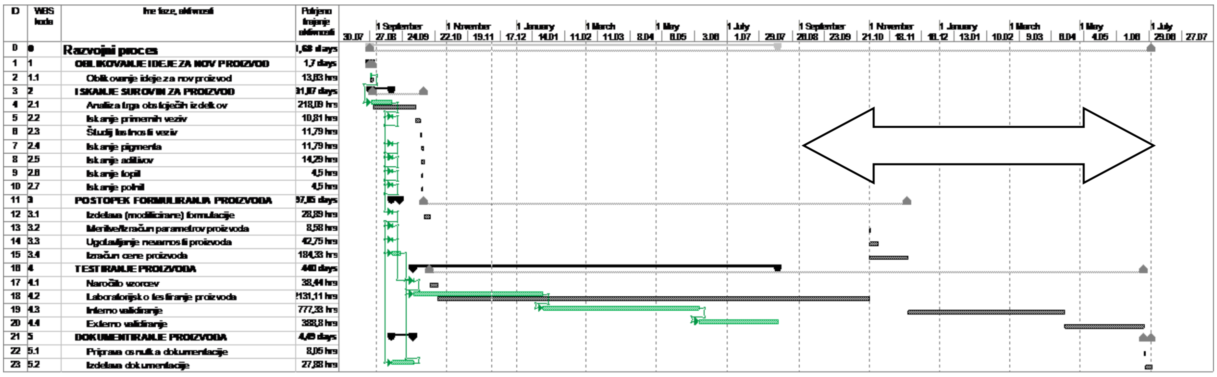


Figure 6: Example of VAD for revamped process

prenovljeni razvojni proces	revamped development process
razvojni proces	development process
razgradnja procesa na prvem nivoju	first-level decomposition of process
razgradnja procesa na drugem nivoju	second-level decomposition of process
oblikovanje ideje za nov proizvod	elaboration of idea for new product
iskanje surovin za proizvod	search for substances for product
postopek formuliranja proizvoda	product formulation procedure
testiranje proizvoda	product testing
dokumentiranje proizvoda	product documentation
analiza trga obstoječih izdelkov	analysis of market for existing products
iskanje primernih veziv	search for suitable binders
iskanje pigmenta	search for pigment
iskanje aditivov	search for additives
iskanje topil	search for diluents
iskanje polnil	search for fillers
izdelava (modificiranje) formulcije	creation (modification) of formulation
izračun parametrov proizvoda	calculation of product parameters
ugotavljane nevarnosti proizvoda	determination of product hazards
izračun cene proizvoda	calculation of product price
izdelava dokumentacije	production of documentation
naročilo vzororcev	ordering of samples
eksterno validiranje	external validation
interno validiranje produkta	internal validation of product
laboratorijsko testiranje proizvoda	laboratory testing of product

5. BENEFITS OF REVAMPED PROCESS

Simulation of the revamped process revealed that this approach to work could significantly speed up the process. In the revamped development process it is possible to save over 47% of the throughput time. The largest saving comes from the reduction in the repetition of slow process functions. There is also significant improvement (of more than 7%) in other parts of the process (see Figure 7).



ime faze, aktivnosti	Name of phase/activity
potrjeno trajanje aktivnosti	Confirmed duration of activity
WBS koda	WBS code
razvojni proces	development process
oblikovanje ideje za nov proizvod	elaboration of idea for new product
iskanja surovin za proizvod	search for substances for product
analiza trga obstoječih izdelkov	analysis of market for existing products
iskanje primernih veziv	search for suitable binders
študij lastnosti veziv	study of properties of binders
iskanje pigmenta	search for pigment
iskanje aditivov	search for additives
iskanje topil	search for diluents
iskanje polnil	search for fillers
postopek formuliranja proizvoda	product formulation procedure
izdelava (modificirane) formulacije	creation (modification) of formulation
meritve/izračun parametrov proizvoda	measurement/calculation of product parameters
ugotavljanje nevarnosti proizvoda	determination of product hazards
izračun cene proizvoda	calculation of product price
testiranje proizvoda	product testing
naročilo vzorcev	ordering of samples
naboratorijsko testiranje proizvoda	laboratory testing of product
interno validiranje	internal validation
externo validiranje	external validation
dokumentiranje proizvoda	product documentation
priprava osnutka dokumentacije	drafting of documentation
izdelava dokumentacije	production of documentation

Figure 7: Time saving in revamped process

In addition to the significant time optimisation, several other benefits are evident in the revamped process. In particular, the process is more environmentally acceptable. Less laboratory testing of formulations that are unacceptable in environmental or price terms entails significantly less unnecessary waste and a lower environmental impact. The revamped process is also more favourable in price terms. Laboratory tests are significantly more expensive than computer simulations. This is attributable to the cost of the equipment and people, and also energy and ingredients. The higher level of innovation in the revamped process should also be emphasised. The formulator's repetitive work in the laboratory is tiring, and eats into time that could otherwise be used for the development of new products. Despite reducing the number of laboratory tests, the revamped process actually increases the chances of developing excellent (optimal) products. When there is a large database of ingredients available to formulators for development (currently it has several thousand units), the probability of an optimal formulation being chosen for a product is much greater than if the formulator conducts laboratory testing on a set of several tens or hundreds of ingredients that are familiar to him/her, that can be obtained or that are held in the local sample base. There is also a greater chance of the quick development and production of niche products in small batches. Because the need for such products is continually increasing, it is possible to work according to the engineering-to-order (EtO) principle, and to use the mass customisation industrial approach *[Wiki, 2019]*.

6. CONCLUSION

At the close of the research, which was intended to determine whether the use of digital technologies could optimise the development of paints and coatings, it can be concluded that there is already an information platform that makes this possible. The AllChemist platform, which was originally intended for the creation of the mandatory documentation that accompanies chemical products, has potential in acting as information support and in optimising the entire development process.

In conclusion, it is reasonable to support and encourage producers of ingredients for paints and coatings to enter data about the ingredients that they produce into a global database. When the body of data about ingredients is sufficiently large and up-to-date, the benefits of using the platform in the development process will be evident in practice.

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