Design of Life Cycle Technologies of Associated Products and Waste in the Process of Preparing the Production of a New Automotive Component

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Abstract. The approach to minimizing the impact of automotive production on the environment, reducing resource consumption and losses due to adequate planning of waste generation in the workplace and the development of processes of their life cycle at the stage of preparation of production of automotive components. The algorithm of design of manufacturing technology of automotive components with the development of processes of generation in the workplace of all types of by-products, aimed at preventing potential losses in mass production. Blocks of calculation procedures of the design algorithm of manufacturing technologies of automotive components are implemented in accordance with the stages of preparation of a new product in the nuclear industry. Calculation of volumes of associated products is integrated as an integral part in the design and calculations of the process of creating a commodity product, for which the structural part of the process is allocated, modeling of the content of intraoperative processes of creating basic and associated products is performed, time chains are formed. The system calculates the volume of commodity and associated products. Schedules for the timely removal of by-products, waste and emissions from workplaces are being developed, with the planning of types of additional work for the maintenance of workplaces. Economic calculations are performed for decision-making by engineering services of the enterprise.

1. Introduction
The world community is increasingly aware of how important it is today to produce products with minimal consumption of resources and minimal impact on the natural environment in the course of the current activities of the main subjects of the industry – companies–suppliers of automotive components. Enterprises independently carry out a number of local projects to prepare production for the release of a new product. How can we help them to prevent violations of environmental requirements?

According to Russian industry standards, technological preparation of production was previously aimed mainly at preparing the processes necessary to ensure the specified quality of commodity products. Process requirements were set out in standardized sets of process documents. Implementation of the industry QMS on ISO/TS16949 requirements at the enterprises-suppliers of automotive components [1] forced the engineering services of enterprises to Supplement these sets with documents and records necessary to regulate the values of key quality indicators.
Meanwhile, the world's automakers impose additional, more stringent requirements on suppliers of automotive components with the content of the standard [2] to ensure compliance with environmental requirements and safety of personnel. Despite the widespread use of environmental management systems, many enterprises have a common practice of corrective actions on the facts identified by the Supervisory authorities of exceeding the maximum permissible emission standards (figure 1 a).

![Diagram of preventive design of life cycle technologies](image)

**Figure 1.** The concept of preventive design of life cycle technologies of associated products a) the basic scheme of work of enterprises according to the requirements of Supervisory authorities, b) the proposed scheme of work of enterprises with the minimization of environmental impact on the environment.

For many machine-building enterprises, the main management tool is to assess the excess of the permissible volumes of already committed emissions and pollution, followed by the elimination of the consequences and causes of violations of environmental requirements. Even enterprises with an environmental management system aim only to maintain an acceptable level of environmental impact, and not to achieve the minimum possible level.
However, it is much more beneficial to prevent potential problems than to address them once they have been identified. This means that this task should be solved before the start of production at the stages of its preparation. To do this, it is necessary to add to the General process of preparation of production procedures for the design of waste, emissions and pollution, depending on the actual content of the processes of creating the main commodity products (figure 1 b).

2. Theoretical part

In mechanical engineering, the basis of any production technology are those or other natural interactions – chemical reactions, mechanical influences, combustion, melting of substances, etc. Specialists create technological systems to obtain with their help a marketable product of the required quality. But in any case, some set of interactions remains unmanageable and generates by-products (radiation, emissions into the soil, water, atmosphere). Many types of equipment consist of at least several functional systems, each of which interact with each other parts of different devices and also create their own passing products. Some of these products are released as they are generated (waste material), and some (waste lubricating oil – accumulate during the exit period).

Developed fundamental algorithm design process the result of which is the calculation of all kinds of by-products generated in the operations of creating a commercial product, as well as secondary operations to remove the primary associated with the calculation resulting in them are already associated secondary products (figure 2).

Various design blocks of the algorithm are performed in accordance with the content of the project of preparation and release of a new product. In the automotive industry according to [3] it is divided into five stages. To solve the above problems, it is necessary to add to the source data to ensure the quality of the commodity product a set of requirements and associated products.

At the first stage, experts should compile a complete register of legislative constraints, such as MPC on classes created by hazardous substances, the analysis of opportunities of the enterprise to comply with these requirements and identified a preliminary resource requirements (preliminary plan-schedule of works)

At the second stage, during the development of a new product, it is necessary to finally establish the requirements for the characteristics of significant associated products. In addition to them, the team of specialists should receive a full range of requirements for the product (quality, productivity, cost) to safety, to the consumption of resources.

The modern task of technological design is formulated in such a way: to form the most adequate model of the production process in order to obtain information for solving any problem of its improvement.

Developing a production operation at the III stage of the project, the technologist implicitly builds its structure. For a new task, it is important to formalize the structure. Otherwise, it will not be possible to link together the interaction in the set of interfaces of the machine system. To select all of them, without exception, have developed methods of modeling operations that produce content and the relationship between all vnutrikorporativeny processes to simple processes that execute in separate working strokes treatment a commercial product.

The content of the technical documentation previously covered only the characteristics of the commodity product. But today, a cross-functional team should not be limited to designing transitions to create product elements. The content of the operating technological system should be elaborated and structured. It is necessary to link the transitions of the generation of all types of by-products with the transitions of the creation of a commodity product, as well as to specify their characteristics with the calculation of the volume of the generated by-products and waste in the workplace. Thus, conditions are laid for planning their life cycle – collection, transportation, delivery and disposal.

For production planning, the construction of temporary chains is provided [4]. It is proposed to manage associated products on the basis of tracking the maximum permissible concentrations of key substances in all production operations. For this purpose, in addition to the document flow – statements of key concentrations of substances are compiled, as well as maps of the life cycles of
waste, emissions and discharges of all types with calculated values and with the determination of the concentration of harmful substances. In some cases, it is also necessary to expand the content of the operating instructions of operators and Adjusters. Management plan concentrations of key substances and contains measures for their reduction. Its implementation is planned through monitoring.

**Figure 2.** Planning the results of technological processes taking into account the formation of associated waste, emissions and pollution in the machine workplace, where I - a typical unit of calculations for each type of product.
During the preparation of the production technology should provide for the fullest possible range of information for cost accounting. Therefore, another mandatory addition is the calculation of resource requirements according to established standards and the final calculation of the planned cost of all processes.

The basic document for the proposed methodology should be a standardized set of technological documentation, supplemented with the necessary annexes for all auxiliary processes, as well as checklists for recording monitoring data of associated products, waste, emissions and discharges.

On the basis of this information, the relevant specialists develop technologies for the life cycle of each type of waste (collection, storage, preparation for sale/disposal, delivery).

Thus, the structure of technological preparation of production does not change. As production operations are developed, it is supplemented with the necessary work groups.

In order to link the technologies of the waste life cycle with the production process, an intermediate document is additionally developed – a map of the fulfillment of tasks for the production of products in the workplace. In these cards it is convenient to present, a full complex of works on service of the equipment, adjustment operations and processes of cleaning. Plans-schedules of these works can be developed for a calendar year.

In mass production (V stage of the project) on the basis of the rules of maintenance of equipment formed schedules and schemes for the collection of these types of waste of each type.

Currently, the authors have formed the structure of the necessary databases for the calculation and standardization of works, as well as a set of documented procedures for different groups of technologies. The developed measures have been tested at a number of enterprises – suppliers of automotive components to the Russian head plants in the form of sets of documentation for the jobs of forming parts on metal-cutting machines and heat treatment jobs.

### 3. Practical implementation

Next, an example of planning the results of technological processes, taking into account the formation of associated waste, emissions and pollution for two different types of by-products – emissions of cutting fluid in the form of aerosol and chip formation in the process of performing the face-grinding operation of processing the support cylindrical element of the part – the camshaft bearing housing on the machine model 3T160.

**Table 1.** Map the flow of technology life cycle emissions of soluble oil in aerosol form.

| №  | Operation          | Type | Basic characteristics of a waste or a product | Basic characteristics of the process |
|----|--------------------|------|---------------------------------------------|--------------------------------------|
| 050 | Circular grinding  | x    | not more than 5 mg / m³                      |                                      |
| 060 | Ventilation        | x    |                                             |                                      |
| 070 | Filtering          | x    |                                             |                                      |
| 080 | Controlling        | x    |                                             |                                      |
| 090 | Cleaning           | x    |                                             |                                      |
| 100 | Storage of spent filter | x |                                             | Tank storage tightness t 20°C ± 5 °C    |
| 110 | Transportation     | x    |                                             |                                      |
| 120 | Utilization        | x    |                                             |                                      |
From the point of view of ensuring environmental requirements in the workplace, the most significant waste of the grinding operation are the emissions of cutting coolant in the form of aerosol (maximum permissible concentration (MPC) not more than 5 mg/m³), the presence of iron dust in the air (MPC not more than 2 mg/m³), and noise - not more than 85 dB (table 1) [4].

The technological structure of the operation is shown in figure 1. The operation is performed in one installation, position, four transitions – roughing and finishing mortise grinding, finishing grinding and nursing. Each transition is performed in one working move.

The technological structure is the basis for the construction of the content model, which integrates all the operational processes inside – delivery and installation and removal of the workpiece from the mandrel, movement of machine modules, switching modes, etc. in the time coordinates (figure 2).

![Figure 3](image3.png)

**Figure 3.** Technological structure of cylindrical grinding machining operations support elements of the bearing of the camshaft.

![Figure 4](image4.png)

**Figure 4.** Inside the operating processes of the circular grinding operation of the camshaft bearing housing support elements processing, embedded in the time coordinate.

The time chain within the operational processes of manufacturing and and their additional technological parameters is the basis for calculating the volumes of all associated products [5]. Thus, the release of lubricating coolant in the form of an aerosol depends on the following technological parameters and conditions of performance within the operating processes: technological grinding modes, the method of supplying lubricating coolant to the cutting zone, the state of the safety devices for sealing the working area from the working personnel. All of them are taken into account in the
process of calculating the volume of associated products. The calculated values of the aerosol formed in the operation are given in table 2.

Table 2. Calculated aerosol emissions to the working area of the grinding machine.

| Elements of technological process | Duration sec. | N the main motion kW | N idling, kW | N total, kW | cardinality | Selection of aerosol, g/m3 |
|----------------------------------|--------------|---------------------|--------------|-------------|-------------|---------------------------|
| Working stroke 040.1.1.1.1       | 5.76         | 2.29                | 1.7          | 3.99        | 1           | 9.42278E-06               |
| Working stroke 040.1.1.2.1       | 30.78        | 0.3                 | 1.7          | 2           | 1           | 2.52396E-05               |
| Working stroke 040.1.1.3.1       | 25.68        | 0.16                | 1.7          | 1.86        | 1           | 1.95836E-05               |
| Working stroke 040.1.1.4.1       | 6            | 0                   | 1.7          | 1.7         | 1           | 0.000004182                |
| Transition 040.1.1.1             | 0.0375       | ---                 | 1.7          | 1.7         | 1           | 2.61375E-08               |
| Transition 040.1.1.2             | ---          | ---                 | ---          | ---         | ---         | 2.52396E-05               |
| Transition 040.1.1.3             | ---          | ---                 | ---          | ---         | ---         | 1.95836E-05               |
| Transition 040.1.1.4             | 0.0354       | ---                 | 1.7          | 1.7         | 1           | 2.46738E-08               |
| Position 040.1.1                 | 1.55         | ---                 | ---          | ---         | 4           | 5.84788E-05               |
| Setting 040.1                   | 1.6          | ---                 | ---          | ---         | 1           | 5.84788E-05               |
| Operation 040                   | 1.75         | ---                 | ---          | ---         | 1           | 5.84788E-05               |
| Tuning cycle 1.1.1              | 19.5         |                     |              |             | 10          | 0.000584788               |
| Adjustment cycle 1.1            | 507          |                     |              |             | 22          | 0.012865328               |
| Production target 1             | 13000        |                     |              |             | 24          | 0.30876787                |

According to the accepted standards, aerosol emissions are normalized depending on the engine power of the main motion for one second of its operation. This rate is $\left[0.041*10\right]^{-5}$ g/kW.

The maximum power of the motor of the main movement of the machine 3T160 is 17 kW. In gross calculations, this nominal power of the electric motor is used by ecologists of the enterprise to determine the maximum possible emission of aerosol. The duration of the emission is taken from the condition of one hundred percent loading of the machine.

In fact, these conditions are not feasible when grinding components. In different working moves of the grinding process of the housing elements, the electricity consumption and their duration are different [6], therefore the volumes of aerosol emissions in different working moves differ significantly (table 2).

Further, having information on the volume of aerosol emission in the grinding operation, the conditions for achieving the maximum permissible concentration (MPC) of aerosol in 5 mg/m3 are checked. The volume of the working area of the machine 3T160 is about 3 m3. During the operation, the aerosol emission is 0.05847 mg/m3. Taking into account the actual volume of the working area of 3 m3, the design aerosol concentration will be 0.01949 mg/m3, which is less than the maximum permissible concentration of 256 times. Thus, the environmental requirements for the calculated values of aerosol emissions are met.

After environmental assessment of emissions, it is necessary to design processes for their removal from workplaces. To remove the resulting aerosol, the local ventilation unit available in the workplace with a capacity of 6 m3 per minute is sufficient. Then you schedule the frequency shift quick-change filters of the ventilation unit, check amnl in aerosol form.
During the performance of the production task for one month in the filter accumulates 0.308 g.
emulsifier. Under condition of preservation of volume of the hulls over the year, the filter delay 3,696
G. soluble oil. The filter retains no more than 100 g of emulsifier and other air pollution without
significant loss of plant performance.

Passport frequency of filter change is 1 time per year. Calculations confirm the passport frequency
of the filter change (more often the filter does not need to be changed). Since the part is treated with
cooling, the cast iron dust is completely washed into the tank and the working area of the machine is
not allocated. Another associated product chip is a waste, having any of the concentrations influence
on the operating personnel the grinding operation.

In the considered circular grinding operation, the chip is formed finely dispersed, mixed with the
wear products of the grinding wheel and the cutting fluid. Its separation from the wear products of the
grinding wheel, capture from the coolant storage tank and transportation to a special container is
performed by a special grinding machine device – a movable magnetic separator. For its processing at
machine-building enterprises, additional technological processes are used – transportation, storage,
heat treatment, briquetting, melting and casting (table 3). The main operations are the sources of
emissions of the burn-up products of the cutting fluid.

To determine the nominal volume of chips formed as a result of grinding, it is necessary to
consistently find the differences between the volume of the workpiece and the semi-finished product
for each working stroke of the production operation. For geometrically simple elements, it is possible
to determine their value using formulas for determining their volumes. For more complex elements,
the determination of the volume and mass of chips is possible only by successive three-dimensional
modeling of semi-finished products as a result of each stroke and the subsequent calculation of the
volume of allowances by the finite element method (figure 3).

The chip mass can be found by the following formula:

\[ M_{chip} = (V_{billet} - V_{specific}) \times \rho_{material} \]  

(1)

where \( V_{billet} \) - volume workpiece prior to treatment in stroke [cm³].

\( V_{specific} \) - volume of the part after processing in the working stroke [cm³].

\( \rho_{material} \) is the density of the processed material [g/cm³].

Other characteristics associated product is a bulk volume that is occupied by the chips during
storage in the container. It depends on the geometric shape of its individual elements and is calculated
by the following formula:

\[ V_{billet} = (V_{billet} - V_{specific}) \times C_{chip} \]  

(2)

Figure 5. Semi-finished products of the camshaft bearing housing, as a result of the grinding
transitions 1 – rough, 2 – finish, 3 – finishing, 4, 5, 6 – nominal allowances of grinding transitions –
rough, finishing, finishing.
where \( C_{\text{chip}} \) – ratio of bulk volume of the chips.

When making technologists of technological documentation, the implementation of three-dimensional modeling of operational semi-finished products in order to perform calculations on the volume of allowance and weight of chips is considered unnecessary, so all chip processing processes are carried out on the actual accumulation in the workplace.

Since the grinding operation is the finishing process of processing and removed allowances are not significant, the bulk volume and mass of fine cast iron chips is also not significant, compared with the rough machining operations. As a result of the monthly production task, 130 kg of chips or 0.0333 m\(^3\) of bulk volume is formed. In this type of chips limiting factor is the process of its coking during long-term storage in the container (adhesion of chip particles in the form of a dense massive lump, accompanied by its oxidation). Coking leads to deterioration of the initial composition of the material, deterioration of the quality of annealing and briquetting. According to the results of the calculation of the volume of chips formed, it is desirable, regardless of the degree of its filling, to adopt a weekly cleaning schedule, combined with the cleaning of chips from other grinding machines that process parts from cast iron. Thus, the calculated volumes of chip accumulation in production operations allow timely planning of further processes of its transportation and processing, as well as to calculate the volumes of secondary by-products associated with heating and briquetting before transportation to the foundry site, as well as to perform calculations of costs for these processes. The calculated yield of other by-products, waste and emissions is calculated according to the algorithm (figure 2) is given in table 3 [4] and allows to plan other auxiliary technological processes related to the storage and processing of waste lubricants, washing liquids, contaminated liquids, solid waste.

**Table 3.** The output of significant by-products of the production task of grinding the support necks of the camshaft bearing housing.

| Name of cycle's | Waste of processed material | Product group |
|-----------------|-----------------------------|---------------|
|                 |                             | Solid | Liquid | Gaseous | Radiations |
| 1. Equipment maintenance | Used lubricants: | | | | |
|                 | - Coolant 175 liters. | | | | |
|                 | - washing liquid 60 liters. | | | | |
|                 | - hydraulic fluids 195 liters | | | | |
|                 | - lubricating oil 20 liters | | | | |
| 2. Monthly production job | Pollution solid | Contaminated liquid | | |
|                 | 1.9 kg | 20 liters | | |
| 3. Weekly production task | Rags cleaning polluted | Contaminated liquid | | |
|                 | 1.5 m\(^2\) | 30 liters | | |
| 4. Operations | Aerosols | Electromagnetic radiation |
|                 | 0.05847 mg | | |
| 4. Working process | Chip | Abrasive dust | Heat, electromagnetic radiation |
|                 | 24.6 g. | --- | | |
|                 | 6.30 cm\(^3\) | | | |
In addition to the found volumes of associated products, the consumption of tools [7], electricity consumption [8-10], the complexity of the operation and the necessary measurement procedures [12] are calculated (figure 2). Calculations are carried out, the costs of processing the items in each component proizvodstvennogo job.

4. Conclusion
As a result of the application of the developed method of process design, a qualitatively new waste management strategy appears: responding to the already identified facts of exceeding regulatory indicators and timely planning of waste generation at each workplace at specific points in time. The application of the developed design algorithm significantly increases the accuracy of the assessment of volumes and terms of work, reduces the planning time of corrective actions, creates conditions for minimizing the consumption of resources. The availability of information on the estimated volumes and locations of occurrences emissions the sharp decrease in risks of infringement of legislation.

The management of enterprises receives an effective means of preventing losses associated with a negative impact on the environment, which allows them to successfully and efficiently meet the requirements. Through the deepening of knowledge about the content of a single operation, it becomes possible to really integrate standards 16949 with the environmental standards of the 14000 series, and the safety standards of personnel of the 22000 series.

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