BENEFITS AND SAVINGS FROM THE DISTRIBUTION OPTIMISATION TOOL

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ABSTRACT
An integrated suite of decision support tools for operations was developed for South Australian Water Corporation between 2012 and 2014. This paper focuses on the Distribution Optimisation Tool (DOT), and the benefits and savings seen by SA Water over the last 18 months since "go-live" on this tool.

Some benefits are direct cost savings to the business or justification of additional operating budget. The DOT has been used as part of the day-to-day operations planning and the longer term annual network operating plans, budget planning and planning for the regulatory period.

The DOT gives SA Water a tool to assess the optimal operating plan for supplying water to the Adelaide metropolitan area and balancing water resources and costs over varying time periods for different planning requirements. Some highlights include:

- "Source to Tap" optimisation tool for whole of network considerations for supply to Adelaide
- Sophisticated and fast solving optimisation algorithms
- Operational cost savings >$400,000 over first 6 months
- Easy development of annual operating plans considering the whole of system in one tool
- Improved investigation and development of operations plans for upcoming 4-year regulatory period
- Faster response and easy updates to data used in the tool, through graphical user interface and automated data feeds (live data for storage levels from SCADA and spot-market electricity tariff forecasts from AEMO)

INTRODUCTION
Water utilities are looking for ways to reduce operating costs, whist improving operational efficiency and reliability of their networks. An integrated suite of decision support tool was developed for SA Water in 2012-2014 to assist with delivering these outcomes for the large and complex Adelaide Metropolitan Water Distribution Network which services over 1 million people.

The decision support tools have been "live" and used daily by the Operations Control Group since late 2014. Five decisions support tools make up the integrated solution:

1. Demand Forecast Tool (DFT)
2. Distribution Optimisation Tool (DOT)
3. Network Operations Model (NOM)
4. Network Status Display Dashboards (NSD)
5. Energy Portfolio Management (EPM)

This paper focuses on the DOT, and the benefits and savings seen by SA Water over the last 18 months since "go-live" on this tool. The DOT provides a clear picture of how demand can best be met by analysing how much water needs to be supplied from the River Murray and from the Adelaide Desalination Plant (ADP) against available water in the reservoirs from either natural catchment or pumping considering pumping and transfer capacities, constraints and costs.

In the process, the DOT determines the optimal low cost way to configure any metropolitan network transfers, optimise treatment/production supply options and optimise the raw water supply network (pumping/transfers/storage levels) over time. The DOT can be run with a four week daily outlook or a two year outlook in weekly increments. This allows users to plan longer term operations, but also look at the day to day short term detail.

PROJECT BACKGROUND
The North South Interconnection System Program (NSISP) was a large construction project that increased flexibility and facilitated north-south transfer capability into the Adelaide Metropolitan Water Distribution Network. The project has enabled additional opportunities for operational optimisation (supply, bulk water transfers, in-network transfers).

The NSISP was the driver for developing the suite of decision support tools to assist with operational planning, network optimisation and efficient operations and decision making for this new flexible network. The DOT was one of five tools developed.

A “Source to Tap” optimisation tool was needed to solve this complex water balance problem taking into account new flexibility and new in-network transfer capacity and optimising water source selection, water treatment selection and network distribution configuration for both the bulk water and metropolitan water supply networks using near real time data inputs.

Existing and previous version of optimisation tools within SA Water did not have the capability to consider in-network transfers and supply flexibility from each of the water treatment plants and the new desalination plant.

Instead of optimising just bulk water pumping (timing) to supplement water collected and stored in storages, optimisation of metropolitan network configuration (in system transfers) and water treatment plant production, plus bulk water pumping and bulk water transfers is now possible and necessary for whole of system operational efficiency, planning and decision making in the short to medium term.

METHODOLOGY

The DOT is a mass balance model of the Adelaide water supply network, taking into account water supply from the River Murray, bulk water reservoir storages, bulk water transmission mains and rivers, metropolitan water treatment plants and the desalination plant, and the metropolitan water distribution network. The water distribution network is represented as 16 demand zones (or nodes), with links between the zones representing allowable flow transfers and connections to water supply (Water Treatment Plants). Figure 1 illustrates the model.

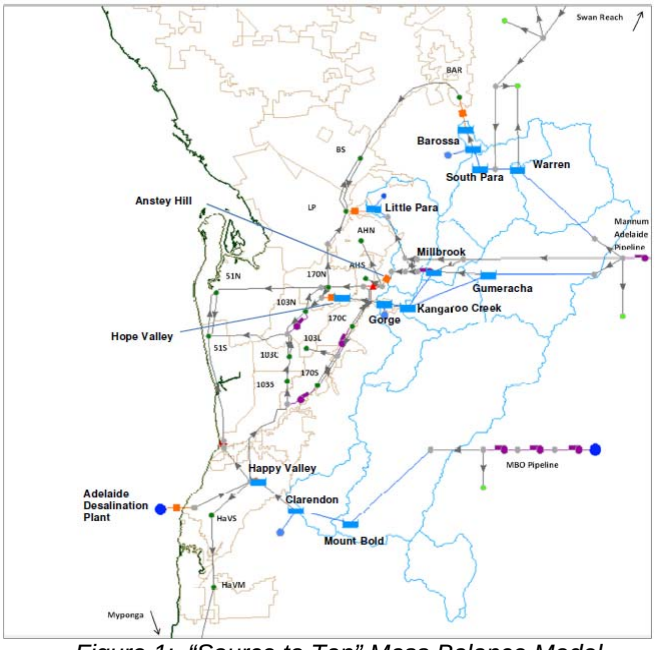

Figure 1: “Source to Tap” Mass Balance Model

The DOT uses a very large Linear Program (LP) with appropriate pre-processing of non-linear hydraulic relationships. The tool can be set to run a long term optimisation (two year horizon with weekly timesteps) or a short term optimisation (4 week horizon with daily timesteps).

The tool is able to solve the optimisation problem using Linear Programming algorithms in under a minute using the processing power of a single PC. The optimisation problem being solved is the flow through each of the links of the mass balance model and the volumes in each of the storages over time. The objective function minimised in the optimisation is the cost of bulk water and metro transfer pumping ($/kWh), cost of water treatment ($/ML) and offset by revenue from two mini-hydros ($/kWh) all considered in the optimisation routine.

There were 7 key business requirements or needs that led to the development of the DOT:

1. Provide daily production rates for each of the water treatment plants and the ADP;
2. Define the daily/weekly configuration of the treated water transfer network;
3. Provide daily transfer volumes across the treated water transfer network;
4. Define the daily/weekly transfer volumes for the pumped supply from the River and from other sources;
5. Define the optimal weekly reservoir levels over a minimum two year horizon using the forecast climate adjusted demands and inflow sequences;
6. Calculate and report the total cost and total energy use in the optimised solution, and
7. Calculate and report the breakdown of cost and energy per facility or transfer in the optimised solution.

Network Linear Programming (NetLP) is an alternative optimisation method used in WATHNET (Kuczera 1992), REALM (Perera & James 2003) and SOURCE (Delgado et al. 2011).

Kuczera et al. (2009) identify some limitations of NetLP; the primary issue being that each timestep is optimised independently so future planned infrastructure outages (e.g. pump maintenance) cannot be ameliorated in earlier timesteps. Counter-criticism of LP is that it uses future unknown data as if it were known (e.g. inflows to storages).

The key benefit of NetLP is its faster run-time. However, that benefit would be trivial for DOT as the LP-based optimisation takes less than 1 minute. LP was ultimately selected as the preferred optimisation method.

In order to use LP, some hydraulic constraints, which are by nature non-linear needed to be

linearised. These non-linearities were discussed in detail in Broad, et al (2015).

SOLUTION

The DOT was built for SA Water as a hybrid tool, using existing technologies in the market and integrating together, plus configuring and in some cases customising the look and feel of the tool to SA Water's needs.

The *Amulet* database and analytics platform by C3 Global (recently acquired by Bentley) was used for data collection, data management and dashboard/report display for selected "published" solutions.

Optimatics' *Optimizer WSS* was used as the optimisation engine for the DOT. *Optimizer WSS* contains the configuration and rules of the water mass balance model, as well as the information and relationships required for the linear programming optimisation objective function and constraints.

Optimizer WSS has a stand-alone desktop user interface for analysis, but for the DOT this has also been integrated with the Amulet database to collect data inputs (live and user defined data sets) and push results back to Amulet for display in a range of web based dashboards and reports management.

Figure 2 shows the following workflow of the DOT.

1. Data management through the DOT Data Entry Dashboard.
2. Data management through the Optimizer User Interface – selection of data sets to be used in an individual analysis.
3. Optimisation analysis, configuring scenarios and analysing the results, and subsequent publishing of select optimisation results to share with the business.
4. Results viewing, analysis and reporting through the DOT Published Sessions Dashboard (along with viewing and reporting of non-optimisation results data, e.g. Water Quality).

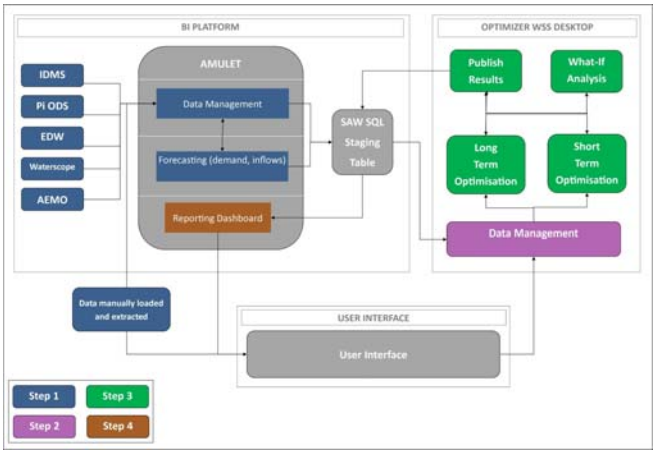

Figure 2: DOT Workflow

The DOT allows SA Water to plan and optimise Adelaide metropolitan water supply operations over the short to medium term. The DOT can run with a daily timestep for a 4 week period or a weekly timestep for a 2 year period. These two modules are also integrated together, allowing the 2 year medium/long term plan to inform the boundary conditions of the short term optimisation runs.

The DOT provideds cost optimised plans for bulk water pumping, transfer flows, reservoir storage levels and network operations configurations over time, as well as providing costs and energy consumption for each plan. Discussion

DISCUSSION AND USER EXPERIENCE

The principal use of DOT was for the cost optimised planning of medium/long and short term bulk water transfers from source to tap, but there have been a range of other use cases experienced by the business. These include:

Long Term Planning:

The long term planning (up to a 2 year window, weekly time steps), of bulk water transfers from river to bulk water storage to customer tap.

Short Term Planning

The short term operations planning (within 4 weeks, daily time steps) of bulk water transfers from river to bulk water storage, production and to customer tap.

Water Security

The establishment of operational rules to ensure Water Security (i.e. sufficient water is available to meet demand), by using a series of scenarios to determine the optimal operating bands up to 2 year outlook.

Sensitivity Analysis

Running a series of plans and varying some inputs to determine the impact on the solution (model outputs) so as to determine the sensitivity of model outputs to a certain input (what-if analysis).

What-If Analysis

Comparing the current plan against a "What If" scenario to determine the impact of that scenario on the model's outputs.

Economic Regulation

Proposing operating plans and budget over a 4 year timeframe to determine costs of operations (what-if analysis) using data and constraints agreed to by the business for the Regulatory period.

Calibration

The model is run against known scenarios with known outcomes to determine the accuracy of the water balance model and calibrate it, if required.

Financial Performance Reporting
Updating the model to the current situation (i.e. set the current configuration) and planning out for the rest of the financial year to forecast cost.

Capital Project Impact Analysis
The DOT can also determine the operational and cost impact of a capital project on network operations. For example, an outage from capital work can be easily built in the DOT to assess the feasibility and maximum allowable duration of the outage as well as potential cost incurred due to the interruption.

Primarily, the DOT is used by the Operation Control Group (OCG) and the operations planning engineers in the team. Annual operating plans and budgets are developed using the DOT and revisited and revised depending on changing conditions in the network or a change in the forecast. This has shortened the time traditionally taken to develop the annual operating plans as well as improved transparency in decision making and confidence in the plan and the relationship between risk and cost.

The DOT also gives the business a tool to quickly investigate, assess and develop optimised operating strategies on daily and weekly basis as part of business as usual and weekly operations planning. Figure 3 shows the DOT user interface.

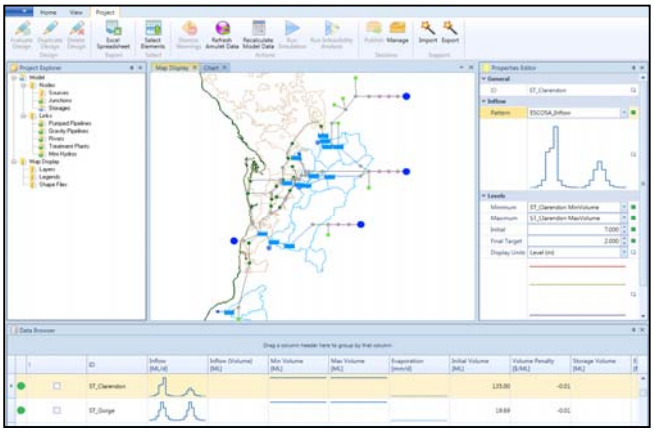

Figure 3 : DOT User Interface

The DOT has allowed SA Water to consider the entire water supply and water balance system for Metropolitan Adelaide in the one model. This has meant that assessment of operating plans or changes in condition takes into account the entire system. Any complex interactions have been captured and the effects of one decision on other parts of the network can be understood and investigated further if needed.

This has therefore reduced the risk that unknown or unconsidered impacts will be missed in the development of operating plans or decision making.

The DOT allows the team to plan and forecast the following over time:

- Pumping Requirements
- Bulk Water Storage levels
- Bulk Water Transfers
- Water Treatment Production mix and volumes
- Metro Transfer Requirements

To do this, a range of input data is required by the tool. Data such as; forecast demands, natual inflows, water treatment cost rates, storage level constraints, power price, pipeline and river flow constraints and asset avaliability are all required. Often there are uncertainties with this and decisions must be made using the best avaliable data and engineering judgment on the expected or most likley conditions.

The DOT has allowed SA Water to run mulitple “what-if” and sensitivity scenarios as part of their operatings planning process. This allows the business to understand the risks, water security and costs of different data assumptions. More considered and transparent decision making is possible, with the impacts understood and quanitifed and the tool easily able to generate un-biased solutions for the given input data and conditions.

The tool also plays an important role in responding to works being undertaken in the network. Planned and un-planned maintence to assets and interuptions in the network are a common occurance that cannot be fully taken into account as part of business as usual planning or annual operating plans/budgets.

The DOT is being used to quickly evaulate alternative operational configuration options and how best to work around interuptions as they occur. SA Water has expressed that this is a very vaulable function of the tool. While some interuptions may be short and not require significant changes to the operating plan, other planned capital works and maintence activities can extend for a number of months on major pipelines or other infrastucture.

The DOT allows operations to assess these outages and develop alternative responding plans for that period. It also allows the business to understand the costs associated with the changes or potential water security issues and risks. SA Water has used the tool to work with asset management and maintence to highlight operational constraints and develop better overall plans that meet the needs of operations and asset management.

BENEFITS AND SAVINGS

The DOT has delivered a wide range of benefits to SA Water. The main benefit experienced by users and the business include:

Time Savings in "Business as Usual" Activities

The tool provides a platform to develop optimised operating plans. The speed of the optimisation engine, the efficiencies in data collection and data entry process and the visualisation of data, solution outputs and reports result in faster and more efficient development of solutions. Time can be spent instead looking at the solution performance, considering different scenarios and making decisions, rather than on setup and run time.

Annual operating plans, budget forecasting, weekly operations and production planning, contingency planning, interruptions planning and water resources management are all part of business as usual for the Operations Control Group at SA Water. A tool such as the DOT has helped to support these activities and allow better evaluation of risks and costs associated with different assumptions, input data and forecast certainties.

Decisions are often made with the best data available at the time and consideration of uncertainties or risk around the data. The DOT has helped to capture and codify the data, network interactions and constraints. It allows SA Water to run sensitivity and what-if scenarios and quickly produce the best solutions for the given inputs. This allows SA Water to have confidence in decision making and be able to back-up and justify decision making, knowing the possible consequences from scenario analysis.

While it is difficult to attribute dollar savings with time savings in "business as usual" activities (as staff numbers have not reduced), previously the development of annual operating plans using manual approaches or combinations of systems and tools would take weeks and months to complete.

These tasks now take weeks, and time is better spent in developing more robust and cost effective solutions. Confidence in the solution and understanding of the impacts on cost and performance with different assumptions or input data would also not have been as great previously, due to the time constraints when developing these plans manually.

Response times to request for information from regulators, development of alternative plans for interruptions or changes in assumptions (changing weather forecasts, demands, costs, inflows, etc.) are also significantly faster and can be done in hours, instead of days which. This can be critical in terms of interruptions and water quality events, as the best alternative action can be determined and implemented in the network. Previously, operations may have had to manage through these incidents costing more to the business in treatment and pumping costs throughout the incident and in recovery mode.

Addressing Operations Assumptions

Developing better solutions, understanding how the network operates and how different assumptions affect solution cost and operating strategy is a key benefit of the tool. The tool has allowed users to challenge assumptions and prove or disprove some operating strategies as best for the network. It also allows the development and capture of knowledge in the business, as well as and contingency planning.

As an example, recent planning and development of an operations plan for the upcoming regulatory period (RBP16) produced solutions that recommended a number of strategies that were not the traditional way of operating.

In a range of scenarios, the DOT recommended maximising throughput at one of the water treatment plants (Hope Valley WTP) due to its low marginal cost to treat. To enable this, water in the upstream reservoirs was transferred in a different way rather than held in reserve at one of the higher reservoirs to minimise pumping later in the year. This traditional view focused on pumping costs and ignores the total network operating cost, including the difference in water treatment plant costs at Hope Valley and Anstey Hill and the advantages in minimising treatment costs and pumping costs over the entire period.

In some areas of the Adelaide metropolitan network there was flexibility to supply different areas of demand from more than one water treatment plant, but in most cases supply areas were fixed. This allowed for reasonably stable and known operating plans, rules and assumptions. The recent North South Interconnection System project has installed a number of new pipelines and pump stations in the network to allow significant transfer capacity through the network and allow for flexibility in operations and importantly flexibility in supply options.

The DOT has allowed the full flexibility of the network to be realised and the cost of treatment, pumping and in-network transfer to be considered when developing operating plans, rather than rely on traditional approaches and rules. This has led to a number of cost savings in operations as well as better understanding of the capabilities and capacities in the network and a systemised way to assess and develop operating plans without bias.

In an alternative example, the lowest cost solutions are also not necessarily the best when the impact and difficulty to operations is considered. There are

two small hydro-generators in the network (Hope Valley EL170 and Seacliff) and revenue from these min-hydros can influence optimal network configuration when this cost benefit is taken into account in the optimisation. However, the benefit of changes driven by hydro-generation revenue is usually small. As a result, SA Water has found that frequent, awkward or risky changes to the network driven by hydro-generator earnings are rarely worthwhile.

The DOT has allowed SA Water to access the impact of incentivising the mini-hydros on the operating plan. Overall lower cost solutions (with the revenue included) were produced, but in this case the reduction in cost did not justify the difficulty or risk. When not incentivised there are still flows through the mini-hydro's (to service demands, transfers, etc.), so there are still revenue gains associated with the operating plan, but the cost/risk profile in this case was not justified to change and drive the operating plan to maximise further use of the mini-hydros. The DOT allows these scenarios to be quickly and efficiently run and SA Water can make decisions based on both cost and risk.

Source to Tap Optimisation

The tool optimises the water supply and distribution system at a high level from "source to tap". This means the impacts of decisions made on the water supply side are considered together with decisions on the water production mix and distribution side for a whole system lower cost and optimised solution without boundary condition assumptions.

With a "source to tap" cost optimiser, SA Water is now able to better take into consideration the marginal cost to treat at each metro Water Treatment Plant (WTP) when determining the optimal network configuration.

SA Water has found the optimal network configuration is sensitive to changes in WTP marginal costs. This highlights the need for accurate treatment costs and for those costs to be calculated on the same basis for each plant, which SA Water continues to put effort into in order to capture the true costs of water production to enable better decision making.

One interesting example from the DOT was the realisation that in wet years the lowest cost operating arrangement will most likely keep the supply area for the high cost Myponga WTP minimised and permit spilling of Myponga Reservoir. Traditionally any spill from a reservoir was seen as waste to be avoided. However, Myponga is a considerably higher cost water treatment plant than Happy Valley and so areas that can be supplied from Happy Valley WTP should be.

The DOT determines this balance of supply and demand and takes into account the treatment costs of both water treatment plants, the available natural inflows that supply these treatment plants as well as any costs of pumping from the river (supply to Happy Valley). As inflows decrease in dryer years this balance can change and the extra cost of pumping does not outweigh the cost of treatment at Myponga.

A tool, such as DOT allows these complex interactions and cost optimisation problems to be solved, as well as allowing the user to test the sensitivity and understand how operating strategies and decisions impact other areas of the network. This has allowed SA Water to better understand the system as a whole and have the tool capture and display these impacts, reducing the risk that some aspect will be missed or ignored.

Cost Savings

The DOT is a cost optimisation tool, so the main and key benefit from the tool will always be to minimise operating costs. SA Water has run a number of benchmarking investigations since "go-live" on the tool. Conservatively, the tool was able to demonstrate a saving of over $400,000 over a 6 month historic period when comparing an optimised operating plan to the actual operations for the same period.

In setting up the benchmark, inflows, demands, costs, constraints and initial conditions were configured to match the benchmark period. The optimised solution showed significant cost savings with the tool able to maximise flexibility in the network to minimise treatment costs and balance major pumping and reservoir levels over time to minimise pumping costs.

SA Water are continuing to benchmark the tool and quantify cost savings, however users and business already have considerable trust in the tool and that the solutions developed are optimised for cost. This means that the tool is currently being used to plan and guide operations on a daily/weekly basis and set operating budgets.

An annual operating plan and budget is based on the best available data and conditions and assumptions about operational constraints and interruptions. The long term 2 year optimised solution will therefore be the best and lowest cost solution, as smaller optimisation timesteps are considered and there is more certainly around data, short term operating constraints and interruptions, optimised solution costs increase. However, managing and optimising around maintenance outages, capacity constraints, unplanned power outages, small capital projects, breakdowns, water quality related difficulties, etc. has been an important use of the tool and lead to a range of cost savings in short term operating plans.

The DOT helps SA Water operations group to make decision on whether, when and how much to pump with its what-if analysis capability and a two-year outlook. In a very dry year like this year, the risk of water scarcity has been minimised and managed well using DOT to develop a pump strategy. This has seen a cost saving in risk management by pumping earlier in the year with reasonable power prices rather than later relying on possible catchment inflows. A good example is that in a similar dry year back to 2012/2013 before the DOT was developed, the decision made at that time without a tool like the DOT ended up with paying high pumping cost in peak summer as early prediction and multiple scenario analysis were not applicable in the old optimisation tool.

The usability of the tool and its ability to solve and optimise for minimum cost given any number of changes to input data and constraints, has allowed SA Water to manage its network operations as optimally as possible and reduced costs even under challenging conditions where cost optimisation is often ignored. Figure 4 shows a result chart.

Figure 4: Optimised Storage Levels and Minimum Allowable Water Security Constraint

CONCLUSION

The DOT has been used by SA Water for more than a year and there have been a range of benefits to the business. Some benefits are direct cost savings to the business or justification of additional operating budget.

The DOT has been used as part of the day-to-day operations planning and the longer term annual operating plans, budget planning and planning for the regulation period. The DOT gives SA Water a tool to assess the optimal operating plan for supplying water the Adelaide metropolitan water distribution system and balancing water resources and costs over varying time periods for different planning requirements.

The DOT delivered for SA Water has been able to satisfy all of the business requirements identified at the outset of the project, as well as a range of other use cases identified through the ongoing use of the tool. This has led to a number of benefits for the business, some of which were expected and others which were not.

- Fast evaluation of solutions for “what if” scenarios and sensitivity runs
- Fast and easy response to changing network conditions or data inputs to re-assess operating plans
- Efficient and robust development of an annual operating plan, testing of assumptions and data sets, risk profiles, cost sensitivity, constraint adjustments, optimise plan for minimum cost
- Use as part of budget planning, and 4 year regulatory period planning
- Use in assessing and measuring the cost impacts to operations of planned and unplanned maintenance work (justification of additional budget needs)
- Modelling alternative operating strategies and challenging historic constraints or operating rules

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